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TAXONOMY AND MANAGEMENT OF VERTISOLS AND ARIDISOLS

PROCEEDINGS OF

FIFTH INTERNATIONAL SOIL CLASSIFICATION WORKSHOP

SUDAN

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CONTENTS

Preface vii

PERSPECTIVES

Constraints to agricultural development in the tropical arid and semi-arid regions of the world 1
L.D. Swindale

Soil classification, soil survey and agricultural development 15
W.M. Johnson

Combatting desertification in the Arab countries 23
A. Osman

SOIL CLIMATIC REGIMES

Calculated soil climate regimes of the Yemen Arab Republic 27
R. Stuart, J. King and A. Van Wambeke

Refinement of taxa based on soil moisture regimes 37
R.L. Guthrie

A quest for an alternative to the use of soil moisture regimes at high categoric levels in Soil Taxonomy 39
W.G. Sombroek

GENERAL ASPECTS OF VERTISOLS

Genesis of Vertisols 47
L.P. Wilding

Vertisols in the collection of the International Soil Museum and some suggestions on classification 63
J.H.V. van Baren and W.G. Sombroek

Relationships between Vertisols and lengths of growing period in the developing countries 69
M.F. Purnell

Application of geostatistics for soil survey and land evaluation 77
B.B. Trangmar, U. Singh, R.S. Yost, and G. Uehara

Application of pedology to plant response prediction for tropical Vertisols 97
R.B. Grossman, W.D. Nettleton and B.R. Brasher

VERTISOLS OF THE AMERICAS, AUSTRALIA AND ASIA

Distribution and classification of the Vertisols of the U.S. 117
R.L. Guthrie and J.D. Nichols

The Vertisols of Hawaii 125
H. Ikawa

Acid Vertisols of Trinidad 141
N. Ahmed

Vertisols of Venezuela 153
J.A. Comerma

The Vertisols of Chile 163
W. Luzio L.

Vertisols of Australia 173
J.W. McGarity

The Vertisols of Thailand 191
P. Vijarnsorn

Vertisols and associated soils of India - Distribution, morphology, chemistry, and taxonomy 205
R.S. Murthy, J.C. Bhattacharjee and R.J. Landey

SPECIAL PROPERTIES OF ARIDISOLS AND VERTISOLS

Mineralogy of Aridisols and Vertisols 221
B.F. Hajek

Relationships between morphological properties and drainage in Vertisols 231
W.A. Blokhuis

The water/air regime of swelling/shrinking soils 243
E. Schlichting

Assessment of soil salinity and alkalinity 253
I. Szabolcs

Ustollic, xerollic and borollic subgroups of Aridisols 263
K.W. Flach, W.D. Nettleton and J.D. Nichols

The hypercalcic horizon 265
R. Tavernier and M. Ilaiwi

Diagnostic horizons of carbonate and gypsum accumulations 269
J.E. Witty

MANAGEMENT OF VERTISOLS

Improved management system for Vertisols in India 275
J.R. Burford and K.L. Sahrawat

Soil fertility management in relation to agricultural productivity in Vertisols of India 285
A.S.P. Murthy, D.P. Viswanath and M.N. Sheelavantar

Mangement of Vertisols for rainfed crop production in the Sudan 317
M.A. Mahmoud

Groundnut production in irrigated Vertisols of the Gezira - Achievements and problems 323
H.M. Ishag and M.B. Said

MANAGEMENT OF ARIDISOLS

Properties and management of Aridisols - A general appraisal 331
H. Lueken and F. Grueneberg

Management of Aridisols in the Sudan 367
M.O.H. Elkarouri

The management of the soils of the Nile Valley 369
H. Hamdi, R. Tinsley and A. Taher

The relationship between soil classification and native plant production and composition on Aridisols and related soils 383
D.T. Pendleton and T.N. Shiftlet

INTERNATIONAL ACTIVITIES

The International Benchmark Sites Network for Agrotechnology Transfer 397
F.H. Beinroth, C.A. Jones and G. Uehara

Laboratory methods and data exchange program for soil characterization (LABEX) 407
L.P. van Reeuwijk and W.G. Sombroek

Proposed procedures for updating Soil Taxonomy 423
K.W. Flach

RESOLUTIONS AND RECOMMENDATIONS 427

APPENDIX

Workshop program 431

List of participants 441

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PREFACE

Since 1975 the Soil Conservation Service of the U.S. Department of Agriculture has established five international committees to critically evaluate and redefine the taxa and definitions of the U.S. system of soil classification, Soil Taxonomy, for soils of the lower latitudes.

In order to provide a forum for discussion of the issues under study by the various committees and to allow the examination of key examples of the soils under consideration in the field, the University of Puerto Rico initiated and helped to organize a series of international soil classification workshops. In close collaboration with host country institutions, previous workshops were held in Brazil in 1977, Malaysia and Thailand in 1979, Syria and Lebanon in 1980, and in Rwanda in 1981. These workshops dealt with the classification of Alfisols and Ultisols with low activity clays, Oxisols, Ardisols, and high-altitude soils of the tropics, respectively. A sixth workshop was subsequently held in Chile and Ecuador in 1984 and focused on the taxonomy and management of Andisols.

The first three workshops were largely funded by the U.S. Agency for International Development (AID) through grants to the University of Puerto Rico. Beginning with the Rwanda workshop, a new AID-sponsored program of the U.S. Department of Agriculture Soil Conservation Service, the Soil Management Support Services (SMSS), provided most of the funds, in part through grants to the University of Puerto Rico.

The Fifth International Soil Classification Workshop held in the Sudan from 2 to 11 November 1982 thus formed part of a comprehensive transnational effort to better adapt Soil Taxonomy to the edaphic conditions of the tropics and subtropics. It addressed the classification and management of Vertisols and Aridisols in general and the mandates of the international committees on the classification of Vertisols (ICOMERT) and Aridisols (ICOMID) in particular.

The Sudan workshop was a joint endeavor of the Soil Survey Administration of the Ministry of Agriculture and Irrigation of the Sudan, the Soil Management Support Services, the Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD), the University of Puerto Rico, and the U.S. Agency for International Development. Major funding for the workshop was provided by AID through SMSS, ACSAD, and the government of the Democratic Republic of the Sudan.

The Sudanese soil scientists comprised in the local organizing committee under the able leadership of Dr. Hassan Hag Abdulla, Director of the Soil Survey Administration (SSA), must be highly commended for the excellent logistic and technical preparation of the workshop. Appreciation is expressed to Mr. Mohamed A. Ali, former Director of SSA, for his early support of the workshop and the willingness of SSA to assume the responsibilities of the host institution. The effective assistance provided by the USAID Mission in Khartoum, especially by its Agricultural Development Officer, Mr. Eric N. Witt, is gratefully acknowledged.

The compilation of the proceedings was a joint effort of the University of Puerto Rico and SMSS. Mrs. Sheila A. Oltz, the managing editor, performed the complex task of editing the technical papers with diligence and competence. USAID/Khartoum kindly provided complete financial support for the printing of the proceedings.

Part I of the proceedings contains the papers presented at the workshop; part II provides reference background on the field excursions and includes complete descriptive and analytical data for the study pedons supplied by the National Soil Survey Laboratory of the USDA Soil Conservation Service. The proceedings thus constitute an up-to-date reference publication on the classification and characteristics of some important Vertisols and Aridisols of the tropics.

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CONSTRAINTS TO AGRICULTURAL DEVELOPMENT IN THE TROPICAL ARID AND SEMI-ARID REGIONS OF THE WORLD

L.D. Swindale

ABSTRACT

The arid and semi-arid tropical regions cover more than one-third of the earth's surface; more than 60 countries have significant arid or semi-arid areas. Southern Asia and Africa immediately south of the Sahara are tropical arid and semi-arid areas comprising low income countries which collectively illustrate all the constraints to agricultural development.

Climate is the ultimate constraint and determines the potential for agriculture. Arid climates are only suited to crop production with irrigation. Poor soils can retard or constrain agricultural development. Physical characteristics of soils are more likely to be constraints than chemical characteristics.

The nature of existing agriculture in Southern Asia and Africa immediately south of the Sahara and prospects for progress in agricultural development are described. In both areas, small and poorly endowed farmers predominate and are the key to progress. Structural and institutional constraints are severe in the African area considered; sociocultural conditions and absolute poverty are severe constraints in Southern Asia. Increased irrigation is possible in Southern Asia, and better use of land is needed in both areas. Improved agricultural technology, meaning input-responsive varieties and improved soil and water management, are essential to development in both areas. Agricultural research and services must be expanded. Only improved technology can force rates of growth sufficient to pay for improved services, ensure increased returns on labor, allow improved soil conservation, and sustain growth in other dependent, economic sectors.

INTRODUCTION

The semi-arid and arid regions of the world cover more than one-third of the earth's surface; more than 60 countries have significant semi-arid and arid areas within their boundaries. The United States, according to

Fauck (1978), has 35% of its land surface within these climatic classifications.

In a brief paper it is not possible to deal with such a vast area of the world. I have chosen, therefore, to limit my paper to two tropical areas, to Southern Asia (specifically Pakistan and India), and to what I will call the Sahel, that is, the seven African countries lying immediately south of the Sahara from Mauritania and Senegambia on the west to Sudan on the east. My reasons for choosing these two regions are: (1) the countries in these regions have more than 50% of their land area in the arid and semi-arid classifications, (2) seven of the nine countries are low-income countries as defined by the World Bank (1982), (3) in 1980 agriculture constituted more than 25% of the gross domestic product and employed more than 50% of the work force, (4) in these countries taken collectively every possible constraint to agricultural development exists, and (5) about 60-70% of the world's Vertisols occur in these countries.

Climate is the ultimate constraint to agricultural development in the arid and semi-arid regions. In semi-arid areas, the growing season is long enough for rainfed crops to be produced. In arid areas, production of the common crops is only possible with irrigation. In the arid areas where irrigation is not available, most of the people are condemned by their own choice to a nomadic existence (Toynbee, 1946) and a low standard of living as judged by all normal indicators.

Although much money has been spent on research on climate modification, there is as yet little prospect of success along these lines, and for the foreseeable future we must accept climate as a fact of life. The ultimate potential for agricultural production in the unirrigated semi-arid and arid areas is predetermined by climate, although we may not yet know what that ultimate potential is.

Soil can limit agricultural development in the arid and semi-arid areas. The soils of Africa in their natural state appear less suited to agriculture than those of Southern Asia, the Vertisols being the conspicuous exception. Soils, unlike climate, can be improved for agriculture through modification, more so by chemical means than by physical, and more so in Southern Asia than in Africa.

Other constraints -- technological, socioeconomic, institutional, and structural -- abound, but they are neither as immutable as climate nor as intractable as soil. Collectively they are much less serious in Southern Asia than they are in Africa, where food production per capita is declining and is a matter of serious concern. The foreign assistance programs of the developed world are gearing up for a massive onslaught upon the constraints to development, particularly agricultural development, on the African continent.

THE CLIMATIC SETTING

The boundaries of the arid and semi-arid regions depend upon the climatic classification that is used. Koppen (1936) divided the world broadly into five climatic groups. The boundary between dry and wet climates was set essentially where precipitation and potential evapotranspiration were equal. The boundary between semi-arid and arid, according to Koppen, would lie where the ratio of precipitation to potential evapotranspiration equals one-half. A much more restricted definition of both semi-arid and arid has been adopted by UNESCO in its map of the arid regions. According to Osman (1982), the upper boundary of semi-arid in this classification is equivalent to the upper boundary of arid in Koppen's classification. Arid is defined by UNESCO at a precipitation to evapotranspiration ratio of 0.2.

ICRISAT, keeping in mind its crop improvement mandate and following the example used by the CGIAR at the time that it first considered the establishment of the Institute, has adapted the climate classification developed by Troll (1965) to define the semi-arid tropics. The boundaries thus determined are similar to those in Koppen's earlier classification. Two subregions of semi-arid are recognized: the dry subregion with 2 to 4½ months in the year where rainfall exceeds potential evapotranspiration, and the wet-dry subregion with 4½ to 7 months in the year where this is so. The arid region has less than 2 months where rainfall exceeds potential evapotranspiration.

The wet-dry subregion of Troll's classification equates approximately to the sub-humid region defined by other climatologists. To this extent it includes areas that might be considered wetter than semi-arid by many observers, but it has the advantage that in both South America and Africa the upper boundary of the wet-dry semi-arid subregion appears to follow closely the boundary separating ustic from udic soil moisture regimes (Van Wambeke, 1981, 1982).

Most of South Asia and the Sahel fall into the tropics however defined. ICRISAT uses an annual temperature of greater than 18°C to define the tropics. Although this boundary occurs considerably north of the Tropic of Cancer, it probably corresponds fairly closely to the boundary of soils with hypothermic or isohyperthermic soil temperature regimes.

The arid and semi-arid tropical regions have high atmospheric water demand and scarce water resources. Total annual rainfall varies considerably from about 400 to 1900 mm, but rainy seasons are short, with the rainfall concentrated from May to October in the northern hemisphere and October to April in the southern hemisphere.

Of the climatic elements important for crop production--rainfall, temperature, and solar radiation--rainfall is the most variable. The coefficient of variation for annual rainfall in the arid and semi-arid regions exceeds 20%. Smaller yearly totals are associated with larger coefficients of variation. Distribution of rainfall within the year is also highly variable and cannot be predicted with any reasonable degree of confidence.

The coefficients of variation for temperature and solar radiation are only of the order of 5%, and potential evapotranspiration is thus more or

less constant from year to year. Small negative deviations in precipitation, either from monthly or annual norms, are all that are required to initiate drought in these regions. For the semi-arid regions, moderate or worse droughts may occur one year in four; for the arid regions, they are normally more frequent. In almost every year in the rainy season there is a period of several weeks without rain.

In most years, the rainy season in the semi-arid regions is long enough for annual crops to grow. The cropping season usually exceeds 90 days. Indeed there is usually excess water in the rainy season, some of which can be stored in the soil, but most of which runs off and causes erosion. In the arid regions, the rainy season is generally too short for annual crops, but even here, intense rainfall and erosion occur. Management of land, crops, and livestock is intimately associated with the inflow and outflow of water.

DISTRIBUTION OF SOILS

The distribution of arable soils in semi-arid tropical regions has been reviewed recently by Swindale (1982). Virtually all the soils in this region have ustic soil moisture regimes and hypothermic, or isohyperthermic soil temperatures. Relief is generally subdued. Alfisols, sometimes quite sandy, Oxisols and Vertisols are the three most important soil orders. Entisols occur in the floodplains of current and fossil rivers. Inceptisols occur in association with the riverine soils on more stable terraces and where soil depth has been insufficient to allow full profile development of more mature soils. Hydromorphic soils are abundant throughout. Salt-affected soils occur in association with other soils and in large areas in depressions, floodplains, and swampy areas.

Aridisols and Entisols, and some Alfisols, Vertisols, and Oxisols occur in arid tropical regions. Salt-affected, calcareous, and gypsiferous soils are common. Textures of soils other than Vertisols are generally sandy.

In Southern Asia and the Sahel there are few Oxisols. The soils of Southern Asia generally have finer textures, more silt, more 2:1 clays and higher exchange capacities than those of the Sahel. Riverine plains with associated fine-textured Inceptisols are more common in Southern Asia. Hills and mountains are also more common, particularly on the northern arid fringe of the subcontinent. The arid region of the Sahel, with its associated Aridisols and sandy Entisols, is much more extensive than in Asia. Slopes are more gentle.

Patancheru series

The red and black soils of ICRISAT are reasonably representative benchmarks of semi-arid zone soils in Southern Asia (cf. Murthy et al., 1982). Patancheru series is a member of the clayey-skeletal, mixed, isohyperthermic family of Udic Rhodustalfs. Patancheru soils have slightly acid loamy sand to sandy loam A horizons, over neutral to mildly alkaline sandy clay loam to sandy clay Bt horizons, over weathered granite gneiss. Mean annual rainfall is 760 mm. Land capability class is IIIs and irrigation sub-class 3s.

Nitrogen and phosphorus are the major nutrient deficiencies in Patancheru soils. The deficiencies are easily corrected using chemical fertilizers with or without additions of farmyard manure. The soils are underlain by strongly weathered parent rock at variable depths. Infiltration and available water are equally variable. Where there is sufficient depth there are 110 mm of available water in the first meter of soil, most of this being held in the upper 60 cm. The soils have poor structural stability at the surface, crust after rain, and when cropped are susceptible to water erosion. Mulching is not really practicable because almost all crop residues are used for animal feed. Land management research has failed so far to find satisfactory and practicable methods of land preparation suited to Indian conditions to prevent runoff and erosion from these soils when they lack vegetative cover.

Kasareddipalli series

Kasareddipalli series is a member of the very fine, montmorillonitic, isohyperthermic family of Typic Pellusterts. Kasareddipalli soils are calcareous and alkaline. Exchangeable sodium reaches 15% at about 1 m. Mean annual rainfall is 760 mm. Land capability class is IIIs and irrigation sub-class 3s.

Nutrient deficiencies are easily corrected by the addition of fertilizer and animal manure. The infiltration rate of the dry soil is very high because of the many cracks. Permeabilities drop to very low values when the cracks close. Under a transpiring crop, the surface cracks open after a few days without rain, and runoff from cropped Vertisols is usually less than runoff from cropped Alfisols. The soils are very susceptible to erosion. Land treatment, particularly the use of ridges, or broadbeds or bunds, reduces soil loss, but crop cover even without land treatment is more effective.

Poor drainage during the rainy season has constrained traditional agriculture to rainy-season fallow and postrainy-season cropping. The practice leads to severe runoff and loss of soil; in a wet year, as much as 10 tons of soil may be lost from fallowed land with less than 3% slope. The problems of poor drainage and erosion susceptibility can both be alleviated by making use of graded beds and furrows linked to the natural drainage patterns of small watersheds.

The ability of the soil to store substantial quantities of water -- more than 150 mm in the first meter of soil -- and to release it readily to plants lessens the effect of variability in seasonal rainfall. Where both rainfall and soil moisture storage are adequate, rainy-season and postrainy-season crops can both be taken. Although irrigation would undoubtedly increase the yield of postrainy-season crops, it is doubtful that the development of regional irrigation schemes for these soils in the semi-arid region can be economically justified.

Chirai series

The Chirai series is a member of the coarse loamy, mixed, hypothermic family of Typic Camborthids. It is a benchmark soil in the arid zone of Northwestern India (Murthy et al., 1982). Chirai soils have moderately alkaline loamy fine sand A horizons overlying moderately alkaline fine sandy

loam B horizons. Calcium carbonate occurs throughout and increases with depth. Mean annual rainfall ranges from 250 to 350 mm. Potential evapotranspiration exceeds precipitation in all months of the year. Land capability class is IVc and irrigability sub-class 3s.

Organic matter and cation exchange capacities are low. Available water-holding capacity is less than 90 mm per meter of soil depth. The sandy surface layers of the soils make them susceptible to wind erosion.

Pearl millet is grown on these soils under rainfed conditions but yields are very low -- only about 300 kg of grain per hectare under traditional practices and never more than one ton per hectare with improved practices. Yields of more than three tons per hectare have been obtained on research fields under irrigation and high management (CAZRI, 1978). The natural vegetation is a thorn savanna, and in rainfed conditions the soils are clearly better suited to grazing than to annual crops.

THE SAHEL

Ustipsamments, sandy Alfisols and related hydromorphic soils also containing much sand are the dominant soils of a vast semi-arid region stretching from Senegambia to Sudan. Natural vegetation is dry savanna. Cropping intensities are low. Torripsamments and Aridisols occur in the more northern arid region. The soils are used for extensive grazing by transhumant livestock. Even in the semi-arid region, animal grazing is important in the total farming system.

Dior series

Dior series is a member of a siliceous, hypothermic family of Typic Ustipsamments occurring at the Bambey Research Center in Senegal. Dior soils are strongly acid throughout, and cation exchange capacities are very low. Mean annual rainfall is 650 mm. Land capacity class is probably IVc.

Low fertility, lack of water, and poor physical conditions are constraints to crop production. The soils are generally low in organic matter, nitrogen, and phosphorus. Potassium, sulphur, and zinc deficiencies show up quickly if the soils are intensively used. Nitrogen management can be difficult because the soils have low buffering capacity and can be acidified easily by ammonium sulphate or urea. The efficiency of nitrogen use can be lowered by volatilization if the fertilizer is not properly covered, and leaching losses occur in wetter years or under irrigation.

Dior soils have less than 100 mm per meter of plant-available soil moisture. Although the soils are often several meters deep, the main cereal crop, pearl millet, does not appear to exploit water much below one meter. The soils have poor structural stability at the surface and are susceptible to wind erosion. Soils with slightly more clay than the Dior soils tend to have rather low total soil porosity and to harden when the soil dries out. The problem is generally limited to soils with up to 18% clay.

Dior soils are associated with sandy Alfisols occurring generally in areas with somewhat higher rainfall and with Torripsamments and Aridisols to the north. Crop yields decrease from south to north. Although lack of water is a major constraint, Penning de Vries and his colleagues (cf Penning de Vries and Djiteye, 1982) believe that during the rainy season nutrients rather than water are the major constraints to the production of adapted and well-suited vegetation.

SOCIO-ECONOMIC CONSTRAINTS IN SOUTHERN ASIA

Poverty

The farmers of Southern Asia generally live in caste-dominated villages in families that usually include dependent parents, brothers, and sisters. Standards of living are low and literacy rates are generally below national averages. Malnutrition and poor health are widespread, but life expectancy has risen substantially in recent years.

Povery is endemic. Most of the rural populations and more than half the total populations of India and Pakistan live in absolute poverty (World Bank, 1978). Similar proportions of people in poverty occur in the neighboring countries of Bangladesh, a humid subtropical country, and Indonesia, a humid tropical country. Thus, the phenomenon of absolute poverty cannot be equated with arid and semi-arid climates. The reasons are partly historic and partly the result of very slow growth in agriculture.

Farm size

Virtually all farmers are small farmers. The resource base and endowments of these farmers have been described by Ryan (1974), Judha et al. (1977) and Jodha (1980). More than 90% of the holdings they surveyed were less than 12 ha in size and 70% were less than 8 ha. The land was usually held in four to five separate fields. The size of holdings tended to be inversely related to rainfall or access to irrigation.

Investments were low. Fertilizers, agricultural chemicals, and improved seeds were used only on land that could be irrigated. There was usually one draft bullock per farm and a total investment of less than $150 on farm implements and machinery. Although only 4% of the arable land was irrigated, 50% of the farmers had access to a source of water for minor or supplemental irrigation.

Crops

Sorghum and pearl millet are the major rainfed cereal crops in Southern Asia. All arable land in the semi-arid region is cropped at least once per year, i.e. the cropping intensity is at least 100%. Even arid-zone soils with only 250 mm annual rainfall may be cropped five years in ten. Where there is access to irrigation, the cropping intensity is greater, but nowhere seems to exceed 120%. Nearly 18 million ha, or 24% of the net sown area

of semi-arid India are fallowed during the rainy season and cropped in the postrainy winter season.

Intercropping, i.e. growing two or more crops simultaneously, is a common feature in the region. It is most common among small farmers and where farmers have least access to irrigation. It gives higher returns per hectare and may spread labor requirements more evenly. It is also a hedge against disaster. Rao and Willey (1980) examined the stability of 94 experiments involving sole pigeonpea, sole sorghum, and sorghum/pigeonpea intercrops. Using a gross return of Rs. 1,000 per hectare as a "disaster" level, they found that sole pigeonpea failed one year in five, sole sorghum one year in eight, but intercropped sorghum/pigeonpea only one year in thirty-six.

Improved production

The key to alleviating poverty is to increase agricultural production by the small, poorly endowed farmer. Although agricultural technology has been greatly improved in Southern Asia in recent years, the annual rates of growth in production are declining because the technology has not yet been successfully extended to the coarse grains and grain legume that many small farmers grow. Adequate and timely supplies of inputs, credit, and services are essential.

It is claimed that increases in yields of up to 30% on rainfed lands and up to 50% on irrigated land would be possible if better soil and crop management were practiced by the farmer and his labor (World Bank, 1978). Seed and fertilizer placement is universally recognized as a major production problem. Its solution requires improved, heavier bullock-drawn equipment, granulated fertilizers and a more effective, better-trained and better-paid extension service.

Improved seed and fertilizer are essential components of almost every form of improved agriculture. Both are in short supply, and the growth rates needed over the next decade or so are staggering. India, for example, will need a 31% annual growth rate in seed production and 13% in fertilizer production to maintain a growth rate of only 5% in agricultural output (GOI, 1981). The distribution network, although well developed to district headquarters and major towns, is still seriously deficient in reaching the villages and probably constrains increased production to a greater extent than supply.

Because there is little additional land for development in this region, increased cropping intensity is the only alternative to increased production per crop. In the rainfed areas increased cropping intensities are most likely on soils with high water-holding capacity such as the Vertisols. In currently irrigated areas where the average cropping intensity is less than 120%, there is much room for improvement, but fragmented land holdings, the land tenure system, and sociocultural traditions are substantial barriers. It is clearly recognized in both India and Pakistan that water mismanagement and poor maintenance of irrigation systems are due in large part to the ancient hierarchy of social relationships within which rural people exist (World Bank, 1978). India much more than Pakistan has the capacity to greatly increase the area of irrigated land. The Sixth Plan envisages a substantial rate of growth in irrigation development -- about 4.7% per year (GOI, 1981).

Growth rates

Annual growth rates in agricultural production of 3-4% sustained over several decades are needed to bring about substantial reductions in poverty, and significant agricultural development. The growth rates required may appear modest until it is realized that historical growth rates in both India and Pakistan, and indeed in the United States, average out to less than 2% per year. Substantial improvements in technology and removal of many of the constraints will be needed to bring about required increases in annual growth rates. Marginal increases through minor modifications of existing technologies and systems of agriculture are not enough (Schultz, 1963). They cannot pay for the increased services required to support the small farmer, cannot force increased returns to labor or increased employment and will not allow improved conservation measures to be installed. They cannot sustain development of agricultural or of other, dependent economic sectors.

SOCIO-ECONOMIC CONSTRAINTS IN THE SAHEL

Community structure

Traditional villages in semi-arid West Africa have a strong sense of community and often a hierarchical system of control. Family units are large and often contain several related adult males and 10-20 people, but nuclear family units comprising a single adult male and his dependents are increasing. Standards of living are low and food production is declining. Because population growth is high, the pressures on land are increasing.

Subsistence farming is much more common here than in Southern Asia. Much of the land is owned communally, but worked by family units which have usufructuary rights to as many as 16 separate, small fields of soils of varying quality around the village. The range in size of holdings is similar to that in India, and the main cereal crops are, again, sorghum and pearl millet (Newman et al., 1980).

Technology

Fertilizers and improved seeds are hardly known and seldom used, but animal manure is used on the fields nearest the village. The use of animal traction is not common but is increasing. Donkeys are the usual source of animal power when it is used, except in Mali where oxen are fairly common. Because the power available is low, soils are seldom ploughed; all agricultural operations are time consuming. Virtually all farm operations are labor intensive -- and labor is in short supply.

Fallowing and burning are used to return some fertility to the soil. Cropping intensities on commonly used land seldom exceed 75% except for the land closest to the village which is used to grow the most important staple cereals. Land far from the village may be cropped only one year in four. Intercropping is common, usually of cereals with cereals or cereals with cowpea. Cash crops such as groundnut, bambara nut, and sorrel are grown on small fields as sole crops.

The countries immediately south of the Sahara are 80% or more arid and semi-arid. They are poor countries of a predominantly rural character with more than one-third of their total population living in absolute poverty and with a critical shortage of well-trained people at every level. Rates of population growth are high, and good production per capita is declining (World Bank, 1978).

These are young countries which have not yet outgrown their colonial past. There is little industry. Exports are mainly of primary commodities in low world demand. The contrast between Africa and Southern Asia is shown in Table 1. Policy formacion and planning for development are not yet well developed. Currencies are overvalued and artificially supported. The wage and salary structure is still designed to fill the governmental and service jobs required by a colonial administration.

Table 1. Developing countries: Product composition of non-fuel exports, 1975.

	Food & Beverages	Non-food Agriculture	Metals & Minerals	Manu-factures	Total
	%				
Sub-Saharan Africa	52	13	26	9	100
Low Income					
Asia	32	17	9	42	100
All Developing Countries	36	9	12	43	100

Taken from World Development Report, 1978.

It is essential that agricultural production be increased. The primary needs are for improved agricultural technology, incentives to farmers, better services of extension, credit and regulated markets (USDA, 1980).

Improved technology is only just becoming available. Agricultural research must be increased and its direction changed towards small farmer needs. Governments are increasing their allocations to research, but lack the personnel and funds to provide adequate support. The ex-colonial powers still provide some support. The International Agricultural Research Centers are trying to increase their inputs in the region in a time of severe financial constraints to their operations. ICRISAT now has approximately one-third of its total program located in these countries.

The abundance of land encourages the use of shifting cultivation and spatially dispersed land holdings. Although this may be a relatively efficient use of the droughty, nutrient-deficient soils under conditions of

low inputs, it encourages inefficient use of what inputs are available, of the very short supply of labor, and of management skills.

Moderate increases in cropping intensity or land productivity are possible under existing conditions, particularly through more efficient cropping systems and better use of intercropping. Integrated improved animal/crop systems hold considerable promise for better use of land and for raising labor productivity through the increased use of animal-drawn equipment.

There are only modest opportunities for increased irrigation (OECD, 1976). In the west, the Senegal and Niger are mighty rivers but have narrow command areas. In the east, the Nile is already well-utilized.

Disincentives to agriculture

Present disincentives to agriculture are many. Food aid is one of the worst. Imported wheat, rice, and maize are sold to the urban population by government parastatal organizations at prices substantially below those of locally produced sorghum and millet. Farmers travel to town to buy the cheaper food.

Many other problems are blamed on the parastatals (Berg, 1980; Harris, 1980). Set up as marketing organizations for exportable agricultural commodities, they now serve as marketing and distribution agencies for both inputs and products while maintaining the dualistic nature of agriculture, to the farmer's disadvantage. The inefficiencies of these organizations have widened the transportation and marketing margins on crops at the expense of the farmer.

With so many problems, effective strategies for development are hard to find. "Agricultural development in Africa has been extremely elusive." (Hogan and Johnson, 1981.) Carefully defined projects have not achieved success, probably because not enough attention has been paid to the problems at the small-farmer level. "The development of a new and reliable high-yielding millet can contribute as much to raising the living standards of millions of poor people as the changes in structure and policy that are also necessary." (World Bank, 1978, pg. 52).

CONCLUSIONS

Many things are needed for the development of agriculture. Growth can be retarded if any are lacking. But not all can be considered constraints in the proper meaning of the word, that is, a force preventing change. Looked at from that point of view, few things, indeed, are real constraints because man's ingenuity has a habit of finding the way around and over all sorts of barriers.

We have to allow the basic resource constraints of climate and soil that limit ultimate possibilities. Plants cannot grow without water. The basic distinction between arid and semi-arid climates depends on water supply; arid climates do not supply sufficient water to allow regular production

of the common crops. Semi-arid climates limit the range of crops that will grow, being often too dry for maize and usually too dry for sugarcane. Within this climatic region the erratic nature of water supply is limiting; too much at one time and not enough at another.

Soil constraints we understand well. They have been summarized recently in two conference proceedings (Swindale, 1978; IRRI, 1980). The real constraints are the permanent characteristics such as texture, erodibility, mineralogy, and exchange capacity. Other things can be changed. Soils with high water-holding capacity, particularly the Vertisols, are the best soils of the semi-arid regions because they integrate rainfall over time sufficiently well to ameliorate or even prevent the effects of short-term drought.

Socioeconomic constraints are very different in Southern Asia and in the Sahel. In the former, structural and institutional constraints are less significant. Deficient policies and inefficient institutions retard development but do not prevent it as they do in Africa.

Poverty is a great constraint. The word connotes a multitude of deficiencies in the human condition that prevent the realization of human capacity. In South Asia, vast numbers of people will still be living in absolute poverty under all growth scenarios.

Development must be a patient process. Bit by bit the pieces must be assembled. What is gained from one project must not be lost in the next. Prospects for more rapid development now exist in Southern Asia because the process has been mastered.

Traditional technologies are constraints to agricultural development in arid and semi-arid regions. Changes at the margin will not suffice. Improved technology, input-responsive crop varieties and improved soil and water management are essential to force much higher rates of growth. Only thus can the rate of population increase be overcome and development be promoted in other sectors of the economy.

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SOIL CLASSIFICATION, SOIL SURVEY, AND AGRICULTURAL DEVELOPMENT

William M. Johnson

World population continues to grow and the need for food increases steadily. Many countries import ever-increasing quantities of food, making them more dependent on other countries. Particularly in developing countries, the need for more food is a critical problem.

To produce more food, existing farmland should be used more effectively, and other soil resources need to be developed for food, oil, fiber, and forage. No country can afford to waste its resources of soil, money, and manpower -- developing countries least of all.

Agricultural production depends on soil, climate, plant protection, and the management skills of the cultivator. Soil conditions themselves modify the influence of climate and plant protection problems, and they commonly provide rigorous tests of the cultivator's management ability.

Most of the world's farmlands were converted from forest, savanna, prairie, or desert a long time ago without the guidance of soil scientists and planners and without benefit of any kind of resource inventory. Many attempts at farming failed, of course, often accompanied by severe damage to soil resources. In time, through trial and error, much was learned about the suitability of different kinds of soils for maize, wheat, rice, and other crops, and the soil responses to management practices. In the Middle East, the evidence of tells and foggaras suggests that cultivation of crops began many thousands of years ago and that many failures and some successes in soil selection occurred before reasonable agricultural stability was achieved.

As farming experience grew, some general principles were recognized and eventually were recorded in written documents (Xenophon, 430-355 B.C.; Cato, 234-149 B.C.; Varro, 116-27 B.C.; Virgil, 70-19 B.C.; Columella, 1st century A.D.). In the latter part of the 12th century a Moorish scholar, Yahya ibn Muhamed, called "Ibn al Awam," wrote The Book of Agriculture, a three-volume treatise on farming, engineering, plant growth, and livestock. He presented a grouping of the soils of the Iberian peninsula that emphasized their suitability for growing food crops. He took much of his information from other writers, including the ancient Greek, Roman, Persian, Spanish, and Moorish scholars. One of his favorite sources was the Sheikh Abu Omar Ben Haggag, who wrote, ". . . the first step in agriculture is recognizing the soil and knowing how to differentiate between the good and the poor one." This generality, first stated about 1,500 years ago, is still valid today.

The function of development planning based on soil surveys "is to substitute for trial and error to the fullest extent possible and to eliminate predictable failures in production and in resource conservation." (Knox, 1977). In most countries of the world at least some information can be had about soil capabilities.

There is a substantial literature dealing with the subject of soil survey in agricultural development planning (see Literature Cited). This paper does not attempt to digest and condense all of this literature, but to review briefly some of the more important points.

AGRICULTURAL DEVELOPMENT PLANNING

Agricultural development includes a whole spectrum of processes aimed at achieving certain social goals. The processes may be industrial, economic, or social. They may be designed to increase the production of food or fiber, reclaim unproductive lands, improve municipal and industrial water supplies, generate new markets for farm products, or even increase educational opportunities for farm children. Of course, not all of these processes depend, even in part, on the quantity and quality of soil resources in the area. In this paper attention is focused on those processes and projects that are soil-dependent. In central country planning, four sequential stages of the process are recognized, each with different requirements for soil information.

First, the area or areas with potential for more intensive agricultural use may be selected. Commonly the choice of areas for development is a political decision. Alternatively, it may be dictated by the existing infrastructure (proximity to transportation, communication, and marketing facilities). Ideally, the quality of the soil resource will be a major consideration in the selection process. A small-scale soil map of the country or the region, with soil descriptions and interpretations, will enable decision-makers to compare the various available areas and to make prudent choices among them.

Second, areas potentially suitable for specific crops or groups of crops may be selected. The same small-scale, general soil map and interpretations used in the first development stage will ordinarily serve for this second stage.

Next in priority is the selection of land and water development strategies for the kinds of enterprises selected in the second stage. Tree clearing, land levelling, irrigation canal construction, and the development of irrigation water supply are operations whose initial investment and maintenance costs may well determine the economic feasibility of the whole project. Both investment and maintenance costs are affected in significant part by soil conditions, including slope gradient, drainage, and soil moisture. A detailed soil survey of appropriate scale and degree of detail is necessary to make firm and accurate appraisals of proposed development projects.

The final stage is to devise management systems for each kind of agricultural enterprise in the development project. Obviously, a detailed soil survey will provide information critically needed to make sound management judgments.

SOIL CLASSIFICATION AND SOIL SURVEYS

Soil surveys provide information about the soils of an area and predictions of their behavior for different uses under specified management practices. Soil maps delineate different kinds of soil areas that are defined and described in the soil survey text. The different kinds of soils are referenced to taxa in some kind of classification system.

In a country as large as the Sudan there are thousands, perhaps tens of thousands of different kinds of soils. Each of these kinds of soil can be recognized, identified, and defined, but to conduct agricultural research on the behavior of each kind would require a very large number of scientists, a great many years, and a huge monetary investment. The amount of research needed for agricultural development can be substantially reduced by using soil classification to transfer appropriate agrotechnology from one area to another, from one country to another, even from one continent to another (Beinroth, 1982; Johnson, 1980).

To be useful for soil survey purposes, and particularly for agrotechnology transference, a soil classification scheme must embrace all of the kinds of soil that are known, both virgin and cultivated.

Many scientists with widely differing training, background, and experience have need to classify soils. Accuracy and consistency of classification can result only if the system used is scientifically objective and quantitative.

To be most useful, the classification should have a heirarchy of categories, with many classes in the low categories and few classes in the higher categories. Such a structure permits the organization and understanding of soil information by classes at different levels of generalization and ensures an orderly scheme for remembering what one knows about soils without unduly burdening his memory. Such a structure also is convenient for designing mapping units for soil maps of different scales and different degrees of detail.

The classification should provide a concept for relating to the conceptual taxa of the system the real soils being classified and the real soil bodies delineated on maps.

Finally, it is helpful if the nomenclature of the classification is phonetic, distinctive, systematic, and easily remembered, with names that indicate something about the properties of the soils and their positions in the system.

In spite of certain deficiencies and difficulties, Soil Taxonomy (Soil Survey Staff, 1975) comes nearer to meeting the above requirements than any other soil classification in use today. With the help of many of the experts participating in this workshop, and others in other parts of the world, further improvements will be made, and these will lead to a closer approximation to an ideal classification.

USES OF SOIL SURVEYS

As previously mentioned, planning for agricultural development requires soil surveys of different scales and degrees of detail. Many years ago, the Soil Geography Staff of the U.S. Department of Agriculture developed 1:1 million soil maps and interpretations for many parts of the world. These maps and reports have been used in "sector studies" of several developing countries to estimate agricultural development potentials. The sector studies can be followed by detailed development planning in selected areas. More recently, the U.S. Soil Survey completed a broad reconnaissance soil survey of the State of Alaska at a scale of 1:500,000. Phases of associations of soil subgroups were used as the "building blocks" for the soil-mapping units. This survey provides an overview of the important soil resource regions of Alaska and identifies areas that have potential for different kinds of development: farming, grazing, forestry, wildlife, and recreation (Kellogg, 1975). These kinds of small-scale soil surveys do not, of course, provide soil information that is sufficiently detailed for either feasibility studies or design and construction of development projects.

After an area has been selected for development, based on a specific farming system, a more detailed soil survey is needed to provide additional information for designing the project and for operational guidance after the project has been completed. In most rainfed farming zones, a detailed survey at a scale of 1:25,000 is suitable, with mapping units designed with phases of soil series or soil families. This provides the detail and refinement to support precise interpretations for alternative cropping and soil management systems. For planning and guiding irrigated farming, more detailed soil surveys, of scale about 1:10,000, are suitable. Soil surveys of even larger scale may be needed in places where horticultural crops are grown, or other high-intensity land-use patterns prevail and individual land holdings are small.

Soil surveys generate acceptance and trust to the degree that they are seen to be accurate, consistent, and reliable. Cline (1977) has proposed a format for appraising the utility of soil maps. The Soil Survey Manual (Soil Survey Staff, 1951) describes procedures for controlling the quality of soil survey field operations and reports. Forbes (1977) presents a tentative checklist for evaluating soil survey reports. The organization and supervision of field, laboratory, and office work must be performed in ways that will assure adequate quality control without excessive costs.

SOIL SURVEYS AND AGRICULTURAL DEVELOPMENT

Cline (1949, 1963) has written benchmark papers on the principles of classification as they relate to soil classification. In his "Lectures on Soil Classification" at Ghent (Smith, 1965), the late Guy Smith discussed the logic of soil classification and the relations between soil survey and soil classification. Beinroth (1978) and Johnson (1978) have discussed soil classification as it relates to soil survey and have reviewed the structure of Soil Taxonomy as compared with other schemes.

The late Charles E. Kellogg (personal communication) often said that, just as the art of sailing governs the design of sailboats, so the making of soil interpretations governs the design of soil surveys. Another way of stating the same principle is to say that the design of a soil survey depends on the kinds and refinement of the soil predictions that must be made from it. By design of soil survey, we refer to the scale of mapping and the minimum size of delineations that will be shown; and to the precision of location of soil boundaries and geographic points.

Some have suggested that time and money can be saved by foregoing rigorous basic soil surveys, and instead mapping directly the suitability classes for cotton, or wheat, or maize. This can be done, and it does take less time and money than the basic soil survey. The difficulty is that suitability of the different kinds of soils for, say, cotton, can be determined only on the basis of present-day soil and crop management practices and present-day cotton varieties. As soon as improvements are made in cotton varieties and in cotton management practices, then the cotton suitability map is useless and all the field work must be done over. If one starts with a basic soil survey, then predictions of cotton yields can be made immediately for present-day conditions. When improved cotton varieties appear and/or management practices are improved, the basic soil map can be reinterpreted to show cotton suitabilities for the improved variety and management.

ROLE OF THE SOIL SCIENTIST

The key figure in the making and using of soil surveys for agricultural development planning is the field soil scientist in charge of the survey (Soil Survey Staff, 1951). He develops the survey design after becoming familiar with the objectives of the survey and with the pedologic conditions in the survey area. He provides leadership in the classification of the soils, the preparation of the soil-mapping legend, the training of staff, the field operations, the collection of soil samples, the synthesis of soil interpretations, and the writing of the survey report. He plays a dominant role in the maintenance of quality control of the survey. This is not to say that he must perform all of the detailed tasks himself; if he did, most surveys would take decades rather than months or years to complete. But he must provide the leadership and management that insures the scientific integrity and practical utility of his soil survey.

Soil scientists of the provincial and national staffs of the soil survey organization play a particularly important role in achieving consistency and accuracy in soil classification, in maintaining high-quality mapping and soil interpretations, and in efficient personnel management at the field level. They are also concerned with the dissemination and use of soil survey information where it is needed. It is usually these soil scientists who interface most directly with national and provincial development planning staffs.

ROLE OF THE DEVELOPMENT PLANNER

Planners and soil scientists need to maintain close and regular communication before, during, and after completion of soil surveys carried out in support of agricultural development planning.

The planner knows what kinds of decisions he will be called on to make concerning suitability of various areas of a country for more intensive farming use. He can identify the kinds of soil information, and the refinement of that information, required to assist him in reaching planning decisions. In other words, he can provide essential guidelines for the design of the soil survey. Working with the soil scientist during preliminary field activities, he can help to assure that the soil survey design will be adequate, but not excessively detailed and expensive, for planning needs.

As the survey progresses, the planner can provide valuable assistance in the testing and evaluation of the survey. He can review preliminary soil predictions and test them in his planning process. If a survey is too general or too detailed, he should recommend changes in the legend and mapping procedure. If the quality of the survey is deficient in aspects critical to his use for development planning, he should recommend more rigorous controls on the soil classification and mapping. Working together, planner and soil scientist can avoid surveys that fail to meet the planner's requirements as well as surveys that are too refined and, thus, too costly for the specified purpose.

When the survey is completed, the planner can assist the soil scientists who prepare derivative maps, charts, bulletins, brochures, and books explaining the soil survey and its usefulness in development planning.

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COMBATING DESERTIFICATION IN THE ARAB COUNTRIES

A. Osman

INTRODUCTION

Desertification process has been defined as an environmental disequilibrium leading to a decrease of agricultural production or to a loss of productive land.

The problem of desertification was identified a long time ago in many places in the world. Only recently, in 1977, the United Nations Environment Program (UNEP) convened an International Conference on Desertification to discuss problems related to the forms, causes, consequences, and measures to be taken for combating desertification. A great number of specialists and decision-makers were involved in this Conference. At the same period and immediately before this Conference, the Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD), with the cooperation of other Arab League Organizations, e.g. the Arab Organization for Agriculture Development (AOAD) convened a Regional Conference on Desertification in the Arab countries. All the Arab countries have participated in this Conference to express their interest and to coordinate efforts for combating desertification in the Arab countries.

This particular interest emanates from the specific climatic conditions in the Arab countries.

ENVIRONMENTAL CONDITIONS

More than 90% of the total area of the Arab countries is arid. The 400 mm rainfall isobyete shows that more than 94% of the total area receives less than this amount of rainfall. This fact has led to more or less the same figures at the country level for the calculation of the soil moisture regime according to the Newhall formula applied by Prof. R. Tavernier in Ghent and Prof. Van Wambeke at Cornell to the Arab countries. Although Sudan has the largest area among the 21 Arab countries, its cultivated lands do not exceed 15%. This country has the largest pastural area and the best possibility for agricultural development.

Table 1. Land use in the Arab countries. (After C A EU, Statistical Yearbook for Arab Countries, 1981).

Country	Total Land		Cultivated Land		Pasture Forest	
	(1000 ha)	(%)	(1000 ha)	(%)	(1000 ha)	(%)
Jordan	9,774	0.7	1,365	2.8	225	0.1
U.A. Emirates	8,360	0.6	11	-	202	0.1
Bahrein	62	-	2	-	4	-
Tunisia	16,361	1.2	4,410	8.9	3,770	0.9
Algeria	238,174	17.4	7,542	15.3	40,380	10.1
Djibouti	2,200	0.2	1	-	250	0.1
Saudi Arabia	214,969	15.7	1,110	2.2	86,601	21.7
Sudan	250,581	18.3	7,495	15.2	115,500	28.9
Syria	18,518	1.3	5,509	11.1	8,983	2.2
Somalia	63,766	4.7	1,066	2.2	37,500	9.4
Iraq	43,492	3.2	5,290	10.7	5,500	1.4
Oman	21,246	1.6	36	0.1	1,000	0.2
Qatar	1,100	0.1	2	-	50	-
Kuwait	1,782	0.1	1	-	136	-
Lebanon	1,040	0.1	348	0.7	86	-
Libya	175,954	12.9	2,544	5.1	7,284	1.8
Egypt	100,145	7.3	2,831	5.7	2	-
Morocco	44,655	3.3	7,840	15.9	17,695	4.4
Mauritania	203,070	7.5	199	0.4	54,384	13.6
Yemen A.R.	19,500	1.4	1,570	3.2	8,600	2.2
Yemen P.D.R.	33,297	2.4	265	0.5	11,545	2.9
Total	1,368,046	100.0	49,437	100.0	399,697	100.0

Among the 1,368,046 ha, the total area of the Arab countries, only 50 million ha are under cultivation, totaling about 3.6%. This area is located in the semi-arid regions. Most of the cultivated area is rainfed agriculture. The irrigated lands cover 8 million ha, about 16% of the cultivated lands.

In many parts of the cultivated land, desertification is occurring under different forms and to a certain extent.

FORMS OF DESERTIFICATION

Several forms of desertification could be identified. Whatever the form of desertification might be, the result is the same--decrease of the cultivated land and decrease of the productivity. One or more of the following factors could be presented.

Climatological

The drought in the Sahel and other parts of the Arab countries has led to many aspects of desertification. The decrease of vegetation, overgrazing, wind erosion, and the deterioration of the natural vegetation cover are responsible for the decrease of the animal production and the development of shifting sand dunes in this area.

Technical

The misuse of land and water in the irrigated area under arid conditions has led to the increase of salinity and alkalinity. A significant part of the Euphrates River basin in Syria and Iraq, as well as in the Nile Valley in Sudan and Egypt, has been disgarded from the agricultural land.

Socio-Economical

The unbalanced economical situation has decreased the net agricultural income. Inflation has the same impact on the agricultural production. As new forms of desertification arose, they were accompanied by the abandonment of agricultural lands and/or increase of the labor cost.

MEASURES FOR COMBATING DESERTIFICATION

National level

Several measures for combating desertification could be considered. Some of them are related to old legislation and inherited rules with regards to woodcutting and grazing rights.

The Hemo are pasture lands that are reserved from grazing for a certain period, a common practice in many Arab countries of the Middle East and North Africa for a long time.

Many Arab countries have established specialized administration for sand dune fixation. Important efforts have been done in Iraq, Egypt, Sudan, and the North African countries. The project of sand dune fixation along the great division between the Tigris and the Euphrates in Iraq is a good example that could be mentioned in this field. Other projects are located in Libya and Saudi Arabia. Important irrigation and drainage schemes

have been executed in the Euphrates River basin in Syria and Iraq and in the Nile Valley in Egypt to reclaim salt-affected soils.

The Forestry Administration in many Arab countries is encouraging afforestation wherever that is possible. A lot of work has been done in Morocco, Algeria, Tunisia, Syria, and Jordan.

Regional

Combating desertification is work carried out at the regional level in many places. A good example is the Green Belt Project in the North African countries through an intergovernmental agreement between five countries covering an area of several thousand sq km where programs on afforestation, drought-resistant varieties of crops and fruit trees, cultivation, and range management have been established. Besides the concerned governments in this Project, regional and international organizations are also involved. ACSAD, ALESCO, and UNEP are participating in this project. Training programs and workshops are also organized to study and to monitor the desertification hazard in this area.

Another project is carried out by ACSAD and four Middle East countries: Iraq, Syria, Jordan, and Saudi Arabia. In this project, studies on the natural resources and the environmental and socio-economic conditions are carried out in the Hamad area covering approximately 20 million ha. The government of the Federal Republic of Germany has also contributed to these studies.

International

International organizations are also involved in desertification control and soil conservation: the International Union for the Conservation of Nature (IUCN), the United National Environment Programme (UNEP), the Food and Agriculture Organization (FAO), and UNESCO are making a good effort for the conservation of the natural resources of the world.

The World Soil Map prepared by FAO, the World Soil Policy established by the UNEP, and the Man and Biosphere Programs of UNESCO are good examples of these efforts.

The Fifth International Soil Classification Workshop is requested to draw the attention of all decision-makers to conserve our soils for the future generation.

CALCULATED SOIL CLIMATE REGIMES OF THE YEMEN ARAB REPUBLIC

R. Stuart, J. King and A. Van Wambeke

The estimation of soil moisture and soil temperature regimes in Yemen is crucial for the correct classification of soils according to Soil Taxonomy (Soil Survey Staff, 1975). Newhall (1972) developed a computer program to make these estimates, using monthly air temperature and rainfall data as inputs. However, these data are scarce in Yemen; for example, monthly rainfall data are available for a few years at 40 sites, while monthly temperature data have been recorded at nine sites only (Map 1). To make full use of the information available, the sites with temperature data were used to correlate temperature with elevation. This relationship was applied to estimate soil temperatures and evapotranspiration at sites with known elevation but lacking temperature data.

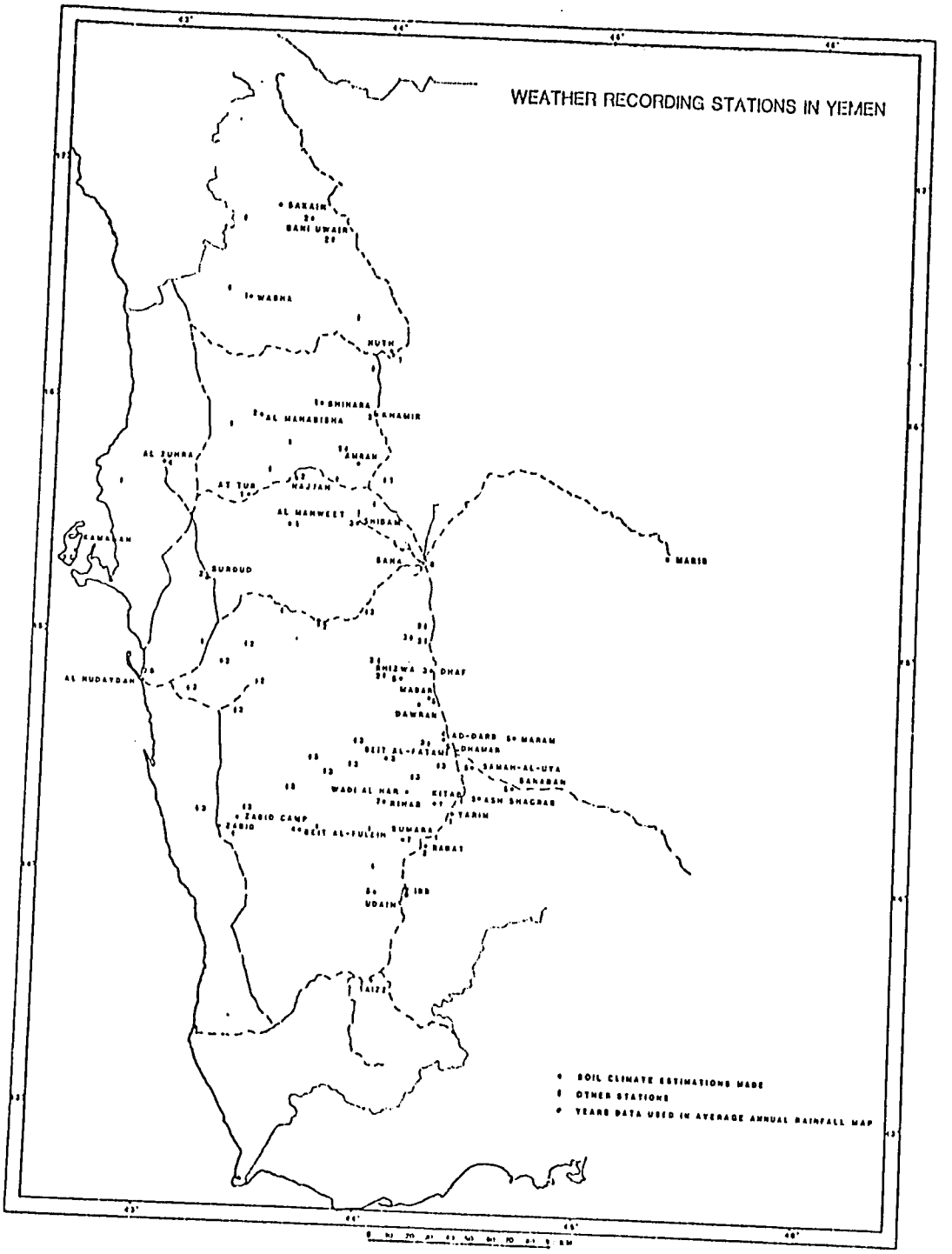
ESTIMATION OF SOIL TEMPERATURE REGIMES BY ELEVATION OF SITE

Nine stations in Yemen have mean annual air temperature and elevation data available (Table 1). The mean annual soil temperature was estimated from the mean annual air temperature by adding 2.5 °C. Regression equations were calculated between elevation and mean annual soil temperature.

Table 1. Observed annual air temperature, estimated mean annual soil temperature, and elevation for nine stations in Yemen.

Stations	Observed mean annual air temp. (°C)	Estimated mean annual soil temp. (°C)	Elevation (m)	Source	Years of data
Al Hudaydah	29.6	32.1	13	1	26
Kamaran	29.6	32.1	20	1	26
Al Zuhra	30.0	32.5	70	5	6
Taiz	23.6	26.1	1500	3	10+
Amran	14.6	17.1	2190	4	1
Sana	15.1	17.6	2300	?	6
Kitab	10.9	13.4	2550	4	1
Mabar	15.3	17.8	2583	2	2
Rabat	11.4	13.9	2743	2	2

Sources: Naval Weather Services, 1974. Worldwide Airfield Summaries; Land Resources Development Centre, 1979. Montane Plains and Wadi Rima Project Report; Wernstedt, F., 1972. World Climatic Data; Gibb, Sir Alexander and Partners, 1979. Development of Wadis Bana and Rasyan, Stage I; Tipton and Kalmbach, Inc., 1979. Development of Wadi Mawr. Appendix B.


WEATHER RECORDING STATIONS IN YEMEN
SAKAIN
BANI UWAIN
WASHA
HUTH
SHINARA
AL MAHABISHA
KHAMIR
AL ZUHRA
AMRAN
AT TUR
NAJJAM
AL MANWEET
SHIBAM
SANA
MARIB
SURDUD
AL HUDAYDAH
SHIBWA
DHAF
MADAR
DAWRAN
AD-DARB
MARAM
BEIT AL-FATAM
DHAMAR
SAMAH-AL-UTA
BANABAN
WADI AL MAR
KITAF
ASH SHAGRAB
RIMAR
TARIM
ZABID CAMP
ZABID
BEIT AL-FULEIN
SUMARA
RABAT
IBB
UDAIN
TAIZZ
SOIL CLIMATE ESTIMATIONS MADE
OTHER STATIONS
YEARS DATA USED IN AVERAGE ANNUAL RAINFALL MAP

The equation with the highest R (96%) value included terms for elevation and elevation squared. This equation is T=32.1-0.069E-0.022E**2, where T is the mean annual soil temperature in degrees Celsius and E is elevation in hectometers (=100 m). However, this equation was found to result in altitude boundaries for temperature regimes at elevations that were clearly out of line with field experience in Yemen. The most probable reason for this was lack of data in the 100-200 m elevation range. Only one station, Taiz at 1500 m, was available in this range.

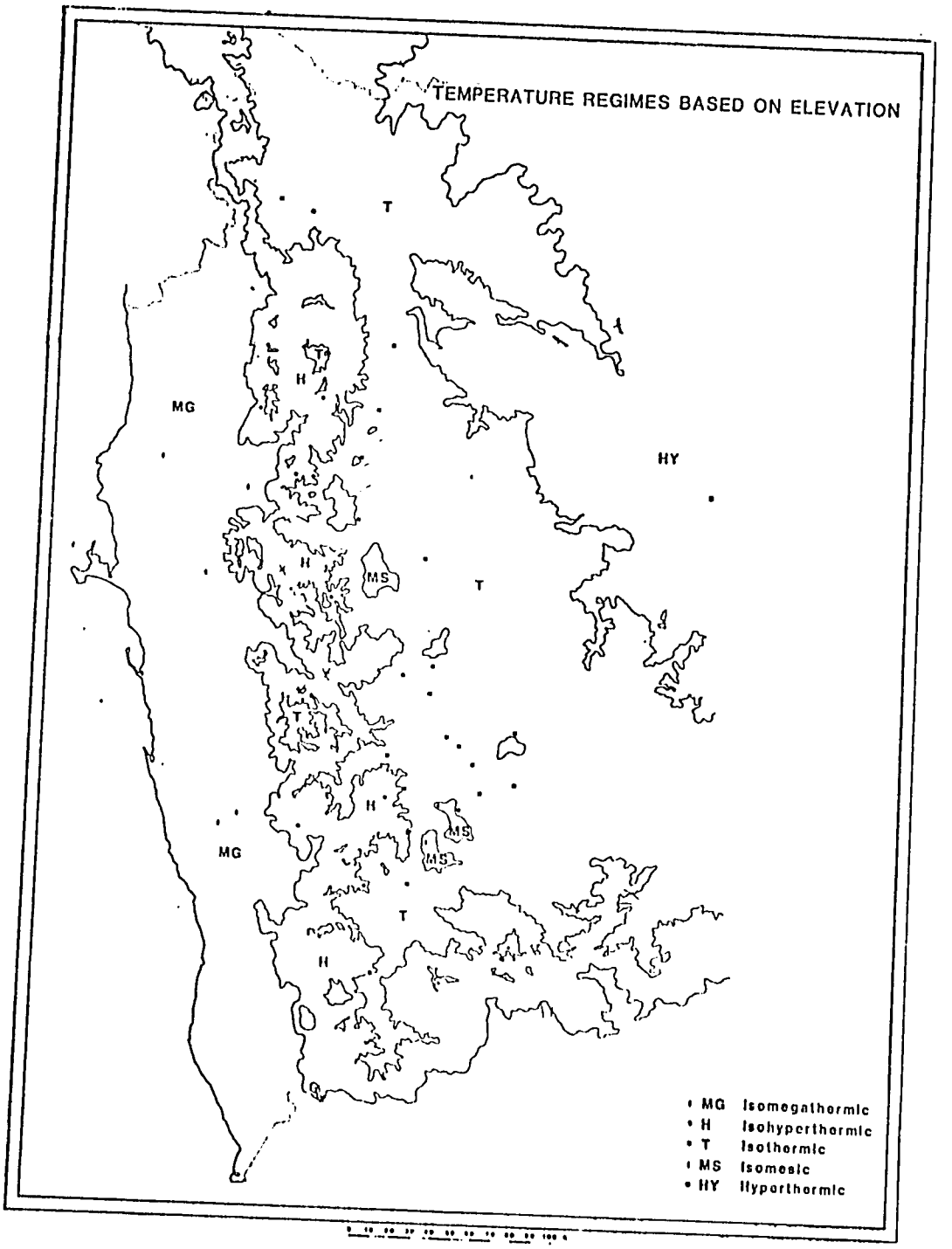
The Yemen climatic situation was considered, in order to select the most appropriate regression equation. The temperature decrease with elevation is primarily a result of adiabatic cooling as winds from the Red Sea and Gulf of Aden rise over the mountains. The adiabatic cooling rate (also known as the lapse rate) is linear, depending on the amount of moisture in the air mass. For dry air masses, the adiabatic lapse rate is 1°C/100 m elevation. For wet air masses, the lapse rate can be as low as 0.4°C/100 m (Petterssen, 1940). The adiabatic heating rate (when an airmass descends into a valley) is the same for both wet and dry air masses, and it is the dry adiabatic lapse rate, 1.0°C/100 m.

The adiabatic lapse rates suggested that a linear rate would serve satisfactorily as a general lapse rate for Yemen. This linear approximation is better for areas along the mountain front, where adiabatic cooling is most important. It is less accurate for highland areas, particularly in areas of steep relief. In these areas, adiabatic heating and cooling take place at varying rates as the air rises and falls over the topography.

A linear equation was used to approximate the lapse rate for Yemen. The equation is T=32.9-0.657E where T=estimated annual soil temperature in degrees Celsius and E is elevation in hectometers. The coefficient of determination for the linear regression is 94%. The lapse rate is 0.657°C/100 m, midway between the wet and dry adiabatic lapse rates.

The above equation was used to relate soil temperatures to elevations. Thus, soil temperature regimes were assigned to elevation ranges. These elevation ranges are given in Table 2. Using Table 2, soil temperature regimes can be estimated for sites where only elevations are known. A soil temperature regime map based on this table is given in Map 2. These temperature estimates also were used to estimate evapotranspiration using Thornthwaite's method (1948).

For most stations for which average monthly temperature data were available, the temperature regimes calculated are iso-temperature regimes. This means that there is little seasonal variation (less than 5°C between winter and summer) in soil temperature. The seasonal temperature variation at 50 cm depth was calculated by reducing the difference between the summer and winter air temperatures by one-third. Al Zuhra, for which monthly temperatures for individual years were available, was iso- two years and non-iso another two years. Marib, for which data are a combination of observed data and data derived from the patterns of nearby stations (Agrar und Hydrotechnik, 1980) is also non-iso, as are nearby stations in Saudi Arabia and South Yemen. These data suggest that latitude and location either east or west of the mountains are the primary influences on whether or not an area is iso or non-iso. However, scant data make it difficult to clearly delineate the boundary in Yemen. It is assumed that all temperature regimes to the west


TEMPERATURE REGIMES BASED ON ELEVATION
T
T
H
MG
HY
H
MS
T
T
H
MS
MG
MS
T
H
MG Isomegathermic
H Isohyperthermic
T Isothermic
MS Isomesic
HY Hyperthermic

of the eastern thermic/hyperthermic boundary are iso-, while the area to the east of this boundary is not.

Using Table 2, the elevation of Kitab suggests that Kitab should be isothermic. However, Kitab is known for its unusually cold temperatures, and the results for the year for which data are available show Kitab as isomesic. This is probably a result of the immediate topography around Kitab. This case points out the care with which these estimates should be used. The generalizations made here need to be interpreted in the light of individual situations.

Table 2. Elevation ranges for iso-temperature regimes (Soil Taxonomy, 1975) appropriate for the classification of soils in Yemen.

Temperature regime	Range of mean annual soil temperature (°C)	Estimated range of elevations (m)
Isomesic	8-15	3790-2725
Isothermic	15-22	2725-1660
Isohyperthermic	22-28	1660-745
Isomegathermic[a]	>28	745 and below

[a]Proposed new soil temperature regime

ESTIMATION OF SOIL MOISTURE REGIMES

Monthly rainfall and elevation data were available for the stations listed in Table 4. The mean monthly air temperatures were attained by calculating linear regression equations for each of the 12 months in the manner decribed for annual soil temperatures. The calculated temperatures were then used in estimating the soil moisture and temperature regimes.

A summary of the estimated temperature and moisture regimes are given in Tables 3 and 4. Table 3 gives results for stations for which observed temperature data are available, and Table 4 gives results for stations for which temperature data were estimated on the basis of elevation. A map of the estimated moisture regimes is given in Map 3.

LIMITATIONS OF THE MODEL IN YEMEN

The Newhall model used in making the soil climate estimations has several important limitations when applied to Yemen. It assumes that there are no significant gains or losses of rainfall due to runoff or inflow. This is

commonly not the case in Yemen, particularly along steep slopes in mountainous areas. For example, much of the precipitation along the Tihama mountain front flows onto the Tihama before it can infiltrate into the subsoil. Thus, many soils on steep slopes with "calculated" ustic moisture regimes may actually be drier than predicted by the model, while wadi areas and concave slopes in the mountains are probably moister.

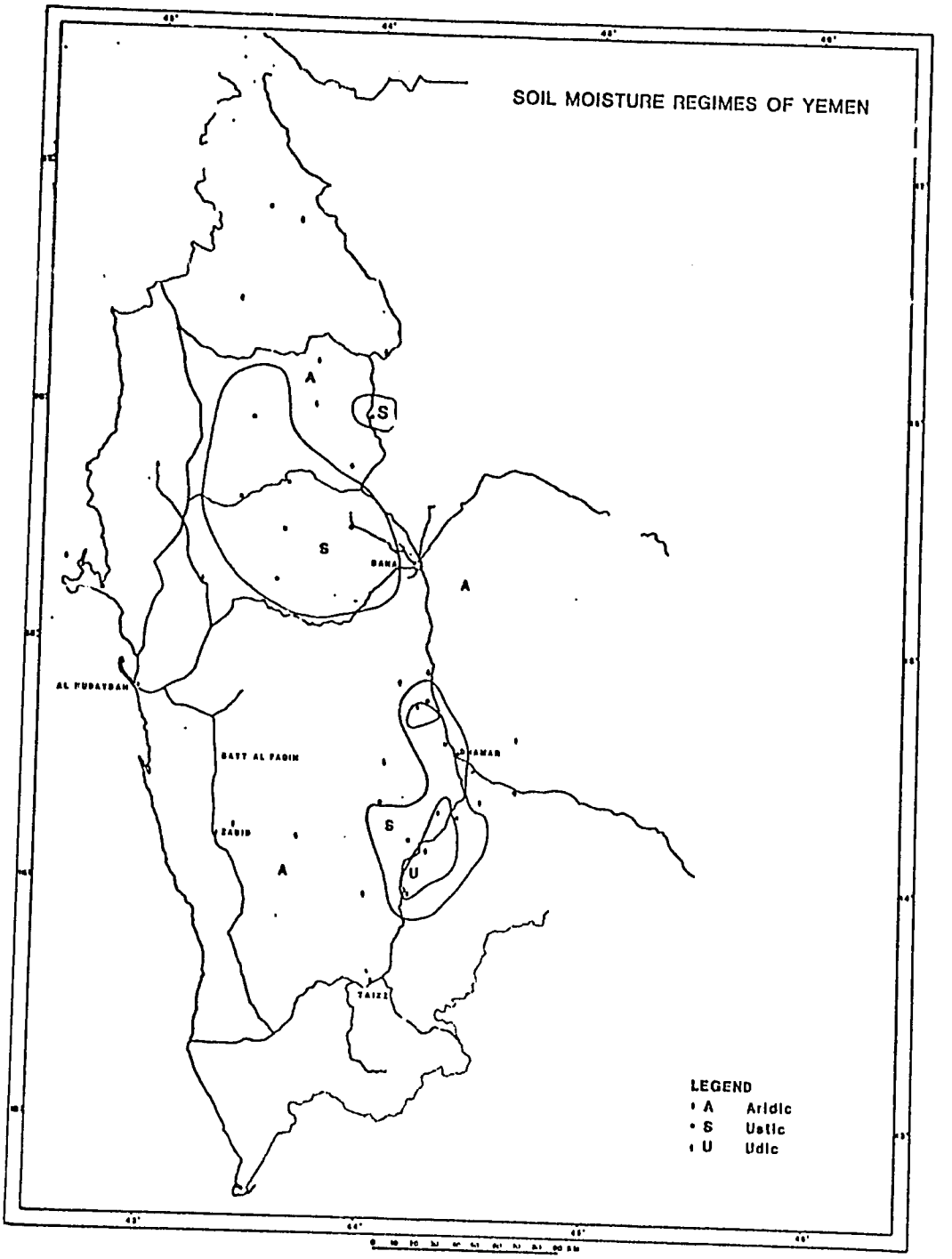
In some parts of the mountains, water runoff is significantly affected by terracing. Water remains in the terraces longer than it would on an unterraced slope. The computer-estimated moisture regimes probably are more accurate in terraced areas because the precipitation is made more effective by the terraces. In these water-harvesting situations, terraced areas may be moister than predicted by the computer model.

Table 3. Results for sites with observed rainfall and temperature data.

Site	Estimated temperature regime	Estimated moisture regime
Al Hudaydah	Isohyperthermic	Aridic
Al Zuhra	Isohyperthermic	Aridic
Amran	Isothermic	Aridic
Kamaran	Isohyperthermic	Aridic
Kitab	Isomesic	Udic
Mabar	Isothermic	Ustic
Rabat	Isomesic	Udic
Sana	Isothermic	Aridic
Taizz	Isohyperthermic	Aridic

Table 4. Elevation and estimated soil moisture regimes for sites with only monthly rainfall data in Yemen.

Site	Elevation (m)	Number of years of data	Calculated mean annual soil temperature	Estimated temperature regime	Estimated moisture regime
Ad-Darb	2750	4	15.0	Isomesic	Ustic
Al Mahabisha	1600	2	22.5	Isohyperth.	Ustic
Al Mahweet	2100	1	19.3	Isothermic	Ustic
Ash-Shagrab	2770	5	14.9	Isomesic	Aridic
At Tur	200	2	31.8	Isohyperth.	Ustic
Bani Uwair	2100	2	19.3	Isothermic	Aridic
Beit Al Fatami	2000	5	19.9	Isothermic	Aridic
Beit Al Fuleih	800	4	27.8	Isohyperth.	Aridic
Dawran	2900	2	14.0	Isomesic	Udic
Dhaf	2625	3	15.8	Isothermic	Aridic
Dhamar	2770	5	14.9	Isomesic	Ustic
Hajjah	1650	2	22.2	Isohyperth.	Ustic
Huth	1850	2	20.9	Isothermic	Aridic
Ibb	1800	8	21.2	Isothermic	Udic
Khamir	2350	2	17.6	Isothermic	Ustic
Maram	2375	5	17.4	Isothermic	Aridic
Rhizwa	2400	5	17.3	Isothermic	Aridic
Rihab	1500	7	23.2	Isohyperth.	Aridic
Sakain	2230	[illegible]	18.4	Isothermic	Ustic
Samah-Al-Uya	2500	5	16.4	Isothermic	Aridic
Sanaban	2300	5	16.6	Isothermic	Aridic
Shibam	2650	2	15.6	Isothermic	Ustic
Shihara	1250	1	24.9	Isohyperth.	Aridic
Sumara	1800	7	21.1	Isothermic	Ustic
Surdud	250	2	31.5	Isohyperth.	Aridic
Udain	1500	6	23.2	Isohyperth.	Aridic
Wadi Al Har	2300	1	17.9	Isothermic	Aridic
Washa	500	1	29.8	Isohyperth.	Aridic
Yarim	2400	8	17.3	Isothermic	Ustic
Zabid	240	6	31.5	Isohyperth.	Aridic
Zabid Camp	240	10	31.5	Isohyperth.	Aridic


SOIL MOISTURE REGIMES OF YEMEN
A
S
S
A
AL HUDAYDAH
BAYT AL FAQIH
ZABID
A
S
U
TAIZZ
LEGEND
A Aridic
S Ustic
U Udic

CONCLUSIONS

Calculations of soil moisture regimes on the basis of atmospheric climate data can give only tentative estimates of climatic conditions in the soil.

Climate classification for large-scale maps which include soil series should take into account observations of soil moisture in the field, the type of vegetation present, and/or the behavior of crops. Whether this is possible in practice is debatable. More experimental field work and measurements are necessary to arrive at reliable predictions of soil moisture conditions, which can be used for land use interpretations.

Soil moisture regimes as defined by Soil Taxonomy provide only broad subdivisions in soil classification. Since they are based on conditions in the moisture control section only, they need to be complemented by more detailed data, including information about the topsoil, if interpretation for plant growth is to be achieved.

Given these limitations, the direct observation of actual field conditions is still critical in making soil surveys which are reliable for land use interpretations. The results presented here are classifications based on the data available and, while tentative, provide a first step toward making correct land use decisions.

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REFINEMENT OF TAXA BASED ON SOIL MOISTURE REGIMES

R. L. Guthrie

The foreword of Soil Taxonomy mentions the need for more precise measurements to refine the definition of certain taxa. Guy Smith, former Director of Soil Survey Investigations in the Soil Conservation Service (SCS), recognized that many definitions of taxa that are extensive in the United States are not perfect, particularly regarding their soil moisture regimes. The weaknesses became apparent when soil moisture regime calculations were compared with the kinds and amounts of natural vegetation produced in major soil areas. Other more striking weaknesses became apparent when Soil Taxonomy was used to classify soils in tropical countries, especially those in monsoonal climates. Soil moisture regime definitions applied to soils that have temperatures suitable for year-round plant growth do not have the same implications for production that they have in temperate regions. Two studies, one for the tropics and one for the United States, are being conducted in an attempt to generate new soil moisture regime definitions.

The International Committee on Moisture Regimes of the Tropics (ICOMMORT) has proposed subdivisions of moisture regimes for tropical areas (Van Wambeke, 1982). Tentative names and definitions of classes have been proposed, but the committee has not proposed new taxa based on the subdivisions.

Several scientists of the Agricultural Research Service are conducting research on the effects of soil moisture on crop production. Saxton, et al. (1982) have developed a computer model called Soil, Plant, Air, Water (SPAW), which combines climatic data with soil and plant properties to calculate consumptive water use. The data used in the calculations can be extracted and summarized to provide probabilities for a given moisture percentage for each soil. The calculations are similar to those of the Newhall model explained in Soil Taxonomy, but the SPAW model is much more flexible. Daily or weekly climatic averages can be used instead of monthly averages, and available water capacities for individual soils can be used instead of the standard 200 mm used in the Newhall model. The introduction of a plant factor adds another dimension. The SCS is testing the SPAW model as a basis for modifying the Newhall model. Testing will be conducted in the following steps:

1. The Newhall model will be run for a number of ustic-aridic transition zone weather stations using new long-term averages supplied by the National Climatic Center, Asheville, North Carolina. Long-term averages are calculated and distributed on tape every 10 years. Calculations made with the new averages will be used as the basis for comparing other models.

2. Estimated or measured available water capacity values will be used to calculate moisture regimes for selected soils near the chosen weather stations.

3. The Newhall model will be modified to calculate soil moisture regimes from the surface of the soil to the base of the moisture control section. The soils studied in step 2 will be used for this test.

4. Calculations similar to those in step 3 will be made using the SPAW model. Many of the problems associated with the applications of soil moisture regime definitions in the United States have centered around the transitions between ustic and aridic and between ustic and udic. Ustic suborders of Alfisols and Mollisols, which are extensive in the Great Plains of the United States, imply the use of soil moisture regimes for differentiae, but only as a possible requirement. The fact that Ustolls and Ustalfs may have udic, ustic, or aridic moisture regimes has led to some difficulties in grouping soils that have similar potential natural vegetation. Compounding this situation is the fact that Udic subgroups of Ustalfs and Ustolls may or may not have udic moisture regimes and Aridic subgroups may have either aridic or ustic moisture regimes.

Before suborder and subgroup definitions are modified, it must be remembered that the criteria used at higher categorical levels are based on soil genesis or they are features that influence genesis. Where possible, management implications were considered in selecting differentiae for the higher levels, but morphological properties were given preference.

Definitions of moisture regimes and of taxa based on moisture regimes need to be reevaluated, but they should be done independently. If moisture regimes are to be used as the only criterion for certain taxa, it seems that the lower categorical levels would be the most logical. The proposed modification of the Newhall model will help to calculate soil-specific moisture regimes rather than a standard value for all soils near a weather station. Until these calculations are made, proposals to modify definitions of taxa should be deferred.

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A QUEST FOR AN ALTERNATIVE TO THE USE OF SOIL MOISTURE REGIMES AT HIGH CATEGORIC LEVEL IN SOIL TAXONOMY

W.G. Sombroek

ABSTRACT

A tentative listing is given of associated features of soil moisture regimes at the suborder level of Soil Taxonomy. These may be used for the development of replacing definitions and naming at that level, relegating soil moisture regimes *per se*, and their subdivisions as proposed by Van Wambeke, to the management-oriented family level.

INTRODUCTION

In the ICOMMORT Circular Letter No. 2, Dr. Van Wambeke submits a proposal for subdivision of the present soil moisture regimes of the US Soil Taxonomy system of soil classification. The implied purpose of the proposal is to make the system more relevant for soil management and agrotechnology transfer. These application aspects of the system are supposed to be concentrated at the family level. Therefore, any adaptation and subdivision of soil moisture regimes should be employed at that level, in a way comparable to the use of soil temperature classes. Such a use of soil moisture regime may have a repetition of the naming of suborder level as a consequence; even a departure from suborder naming may be required, viz. if one wants to put the main boundaries of the regimes somewhat differently at family level to make them more meaningful for management purposes. Omitting soil moisture regimes at suborder level would break up the whole structure of the classification system, which should be avoided. It is implied in Soil Taxonomy, however, that the criteria used at the higher categories are either the result of genesis or important for genesis.

The application of soil moisture (and temperature) regimes in this respect is meant to determine the conditions under which genetic processes take, or have taken, place in soils. In fact, in a number of cases this relationship has already been "translated" into measurable characteristics ("the marks") other than moisture and temperature ("the causes"). Wherever such marks can be defined, they should, in the rationale of Soil Taxonomy, have prevalence in the definition of the higher-category units over the soil moisture criteria themselves (cf. Guthrie's contribution at this Workshop). One may, therefore, try to do this systematically throughout the suborder level, at the same time coining new prefixes to avoid overlap or a confusion

with the detailed soil climate denominations at family level.

A tentative scheme for the associated features or marks of soil moisture regimes at high categoric level is given below, based on the example profiles in USDA Agricultural Handbook 436. To elaborate the scheme, many more profiles would have to be checked. However, such a checking exercise can be restricted to the USA soil situation, because any proposed changes should fit with the US soils pattern to have any chance of becoming accepted. Elsewhere, and in the tropics and subtropics in particular, such changes can be accepted easier because the use of Soil Taxonomy in the countries concerned is often still in an experimental stage, or complementary to a national system.

The basic assumption is that a udic soil moisture regime (in mesic or warmer climate) implies a continuous downward movement of ions; an ustic moisture regime, a seasonally interrupted downward movement; a xeric moisture regime, a seasonally downward movement accompanied by a seasonally upward movement of ions; and an aridic moisture regime, a nearly continuous upward movement. This should be reflected not only in the clay mineralogy (which, unfortunately, figures only way down in the system), but also in the pH-BS sequences in the pedon and the depth of appearance of free carbonates; the latter feature is sometimes already part of the definitions at suborder level.

Notes:

a) pH stands for pH-H_2O; BS stands for base saturation by sum-of-cations method; Ca stands for free carbonates presence of more than weak effervescence (>1%).

b) All "decrease" or "increase" tendencies are taken to start below the plow layer, since management practices may have modified the virgin condition in that layer substantially; a decrease may be regular or irregular, i.e. it may be interrupted by one or two minor increases.

c) Only profiles recorded in Soil Taxonomy are taken into consideration; any apparent trends should be tested on a substantial number of other profiles in the USA, and can only then be fully quantified and made mutually exclusive

SOILS WITH UDIC MOISTURE REGIME

Orthox suborder

In the Orthox suborder a udic moisture regime is only implied in the definition; the soils should be non-aquic, non-torric, non-humic, and non-ustic.

Trends. The pH sequence is often irregular but the BS is decreasing with depth till at least 200 cm (four out of five profiles); the Ca is absent till beyond 300 cm (?).

Udult suborder

At the Udults a udic moisture regime is specified in the definition. They should moreover be non-aquic and non-humic.

Trends. The pH is decreasing or approximately equal with depth till at least 150 cm or till near (30 cm?) the parent rock (five out of six profiles); the BS is decreasing or equal till at least 100 cm (six out of six profiles); the Ca is absent till below 200 cm.

Udalf suborder

At the Udalfs a udic moisture regime is specified in the definition. They should moreover be non-aquic, non-boric, non-ustic, and non-xeric.

Trends. The pH is decreasing or approximately equal with depth till at least 120 cm or till near (30 cm?) the parent rock (seven out of eight profiles); the BS is decreasing or equal till at least 80 cm (seven out of eight profiles); the Ca occurs only below 150 cm; or at more than 50 cm below the base of the argillic horizon (see definition of Ustalf).

Udoll suborder

At the Udolls the udic moisture regime is only implied in the definition. They should be non-albic, non-aquic, non-rendic, non-xeric, non-boric, and non-ustic.

Trends. The pH is decreasing, equal, or slightly increasing (less than 0.3 unit) till at least 65 cm (five out of five profiles); the BS is decreasing or equal till 30 cm (four out of five profiles); the Ca occurs only below 90 cm, or a calcic/gypsic/ca horizon is found only below 150 cm or below 50 cm beyond the base of an argillic or cambic horizon (see definition of Ustoll).

Udert suborder

At the Uderts a udic moisture regime is only implied in the definition. Their cracks should be less than 90 days open, and they should be non-xeric and non-torric.

Trends. The pH and BS are not decreasing with depth or only over a short distance (40 cm?), but the Ca occurs only below 90 cm (two out of two profiles).

SOILS WITH USTIC SOIL MOISTURE REGIME

Ustox suborder

At the Ustox an ustic moisture regime, combined with isothermic, thermic, or warmer temperature, is specified in the definition. They should moreover be non-aquic, non-torric, and non-humic.

Trends. The pH is stable till more than 100 cm depth; the BS is stable or decreasing (?); the Ca is absent till below 200 cm (only one profile given in ST; Oxisol order moreover provisional).

Ustult suborder

At the Ustults an ustic moisture regime is specified in the definition. They should moreover be non-aquic, non-humic, and non-udic.

Trends. The pH is equal or only slightly increasing (less than 0.3 unit) with depth till at least 100 cm; the BS is equal or slightly decreasing (?) till at least 100 cm; the Ca is absent till ... cm (only one profile given in ST).

Ustalf suborder

At the Ustalts an ustic moisture regime is specified, but only as one of the possible requirements in the definition. The soils should be non-aquic and non-boric.

Trends. The pH is equal or only slightly increasing (less than 0.3 unit) till at least 50 cm depth; the BS is equal or slightly increasing till at least 50 cm depth; the Ca is found only below 60 cm, but within 150 cm c.q. 50 cm below the base of the argillic horizon (see definition).

Ustoll suborder

At the Ustolls an ustic moisture regime (or ustic-aridic) is specified, but only as part of the definition; the soils should be non-albic, non-aquic, non-rendic, non-xeric, and non-boric.

Trends. The pH increases by more than 0.3 unit within 65 cm depth (four out of five profiles); the BS increases with depth (?); the Ca occurs within 90 cm, or a gypsic/calcic/ca horizon is found within 150 cm depth c.q. within 50 cm of the base of an argillic or cambic horizon (see definition).

Ustert suborder

At the Ustert an ustic moisture regime is only implied in the definition. They should be non-xeric, non-torric, and non-udic.

Trends. The pH and BS are increasing with depth; the Ca occurs only below ... cm but within 90 cm.

SOILS WITH A XERIC SOIL MOISTURE REGIME

Xerox suborder

No Xerox foreseen in ST.

Xerult suborder

At the Xerults a xeric moisture regime is specified in the definition. They should moreover be non-aquic, non-humic, non-udic, and non-ustic.

Trends. pH and Bs decreasing (?) with depth; no Ca till ... cm (only one profile given in St; representative?).

Xeralf suborder

At the Xeralfs a xeric moisture regime is specified in the definition (or xeric-aridic with massive + hard). They should moreover be non-aquic, non-boric, and non-ustic.

Trends. pH and BS increasing with depth (three out of four profiles); the Ca may occur throughout, but its maximum is found below 50 cm (?).

Xeroll suborder

At the Xerolls a xeric moisture regime is specified in the definition (or aridic-xeric). They should be moreover non-cryic, non-albic, and non-rendic.

Trends. pH and BS are increasing with depth (seven out of seven profiles); the Ca may occur throughout, but its maximum is found below 50 cm.

Xerert suborder

At the Xererts a xeric moisture regime is only implied in the definition. Their cracks should be open for more than 60 days, and the temperature should be thermic or mesic.

Trends. pH and Bs are increasing with depth; the Ca, if present, has a (weak) top only below 50 cm.

SOILS WITH A TORRIC OR ARIDIC MOISTURE REGIME

Torrox suborder

In the Torrox the torric moisture regime is specified in the definition. They should be non-aquic.

Trends. pH and BS increasing with depth (?); the Ca is absent till ... cm? (only one profile given in ST).

Torrert suborder

In the Torrerts the torric moisture regime is only implied in the definition. Their cracks should be open for more than 60 days, and the temperature should be hotter than thermic or mesic.

Trends. The Ca occurs throughout but has a weak bulge? (one profile only in ST).

Aridisols

In the Aridisols an aridic moisture regime is specified in the definition, in this case even at order level, but again with some qualifications. The soils should be non-aquic, nonn-histic, non-spodic, non-oxic, non-mollic or -ustic, and non-vertic. When they have an argillic or natric horizon they should have an aridic moisture regime (and an epipedon that is not both massive and hard or very hard). If they do not have such an horizon then they should have either a salic, petrocalcic, calcic, petrogypsic, gypsic, or cambic horizon or a duripan, combined with either an aridic moisture regime or an ustic or xeric moisture regime with presence of some free salts.

The above demonstrates that the aridic moisture regime *per se* is not the single criterion. On the other hand, the definition implies that normally no Ultisols, Alfisols, and Inceptisols, including Andepts, can occur in zones with aridic climates. Examples, however, abound (Africa, Australia) of old, stable land surfaces in present-day aridic environment where the soils have well-developed, low-activity-clay argillic or cambic horizon, dating from former, more humid periods. In other instances, soils may occur in aridic environment where a special parent material, like an acid aeolean deposit, volcanic ash, or sulfuric material, exerts a major influence on the soil characteristics. In both cases the resulting intrinsic properties of the soils are often not masked by an engulfing or encrusting calcic horizon or the like. In other words, the aridic environment has not, or not yet, imprinted itself on the soil in a predominating way. There is no overriding result of genesis in an aridic environment, hence their inclusion with Aridisols is unwarranted.

Trend c.q. *hypothesis.* Conceptually, "developed" desert soils have high pH, Bs, and Ca throughout the profile, expressing itself often in (petro)-calcic/gypsic/salic horizons at depths affecting plant growth.

CONCLUSIONS

From this preliminary checking of trends per order of the various soil moisture regimes, it would appear that:

- the soils with udic regimes have a dominantly decreasing base saturation = alkalinity;

- the soils with an ustic regime have a downwardly, approximately equal (iso) or slightly increasing alkalinity;

- the soils with a xeric regime have dominantly distinctly increasing alkalinity;

- the soils with a torric or aridic regime have dominantly a complete alkalinity throughout: per-alkalinity.

If one wants to apply management-oriented subdivisions of soil moisture regimes at family level and, therefore, replace "udic", "ustic", and "xeric" at suborder level (and at great group level for the Entisols) by some other formative element, then the use of dec(a), is(a), in(a), and per(a) may be considered. The following partial scheme illustrates the proposal:

Aqualf →	same	Aquox →	same	---	---
Udalf →	Decalf	Orthox →	Decox	Udipsamment →	Decapsamment
Ustalf →	Isalf	Ustox →	Isox	Ustipsamment →	Isapsamment
Xeralf →	Inalf	---	---	Xeropsamment →	Inapsamment
---	---	Torrox →	Perox	Torripsamment →	Perapsamment

The new definitions may comprise a combination of pH-BS sequence and depth of occurrence of free carbonates, specific per order c.q. suborder.

For the soils having obtained their features predominantly from the action of a torric or aridic moisture regime, an order narrower than the present Aridisols may be defined, with the tentative name *Eremosols* (c.f. Appendix).

In all cases, the necessary mutually exclusive quantification of limits would require very ample testing, on U.S. benchmark soils in first instance.

APPENDIX

Tentative definition of an Eremosol order
(proposal Bouyadjev, Flach, Segalen, Razik, and Sombroek at IRB meeting, Sofia, June, 1981; slightly modified)

Eremosols are soils having:

- a calcic, petrocalcic, gypsic, or petrogypsic horizon with 125 cm or evidence of redistribution of $CaCO_3$ or gypsum, and other evidence of a cambic horizon,
  or an electrical conductivity >2 mmho within 75 cm (or any other appropriate depth), not connected with a high groundwater table,
  or pedogenetic palygorskite (not applicable to "cold" deserts)

and <u>lacking</u> (within 75 cm or any other appropriate depth):

- vertic characteristics
- a mollic or umbric epipedon (or more than 0.5% C- or else, related to the clay percentage)
- strongly saline (solonchak) characteristics
- sodic (solonetz) characteristics
- a gley (Go) horizon
- hydromorphic properties over a slowly permeable horizon (planosolic)
- arenic or fluventic properties
- a spodic horizon or andic properties
- an oxic horizon
- an argillic horizon of CEC clay < 36 meq (ferralic or fersiallic), unless overlain or engulfed/masked by calcic or gypsic materials.

GENESIS OF VERTISOLS

L.P. WILDING

ABSTRACT

Three pedogenic models of Vertisols are presented and evaluated. High shrink-potentials of these clayey soils are attributed to moisture sorption-desorption at external surfaces of clay aggregates or individual clay domains rather than hydration-dehydration of interlayers. This process would account for physical instability, extensive cracking, and development of slickensides, gilgai microrelief and tilted wedge-shaped subsoil structure aggregates in Vertisols.

Pedoturbation is an active process but insufficient to account for rapid formation of the above physical properties or to obliterate long-term systematic pedogenic translocations of organic matter, soluble salts, and carbonates. Cambic horizons should be recognized in subsoils of many Vertisols rather than physically mixed AC horizons. For pedogenic purposes, gilgai microlow and microhigh elements should be sampled separately over a constant area of 1 m^2. Within a 1 m^2 area sampling unit, CV's are about 10-20% for soluble salts and 5-10% for exchangeable properties, pH, and calcium carbonate equivalent. Microfabrics of Vertisols reflect microshear failure in the form of vosepic, masepic, skelsepic, and lattisepic plasmic fabrics. Vertisols developed from mafic-rich igneous or metamorphic rocks may develop argillic horizons as an early precursor pedogenic stage to extreme shrink-swell activity.

INTRODUCTION

Vertisols are a unique soil resource that comprise nearly 260 million hectares on the face of the earth (Ahmad, 1983). The genesis of these soils is strongly influenced by soil movement and turbation, hence the name. While turbation has been emphasized in the literature, there is mounting evidence that the rate of churning is not sufficient to obliterate long-term pedogenic losses, translocations, and accumulations of organic carbon, carbonates, and soluble salts. Further, pedoturbation has not destroyed formation of compound prismatic-blocky structured cambic horizons (Blokhuis, 1982; Ahmad, 1983). Contentions that Vertisols should really be a subcategory of Entisols are unfounded.

Space does not permit duplication of the voluminous literature on Vertisol properties and genesis. Readers are referred to excellent reviews of morphology, classification and genesis of Vertisols by Blokhuis (1982) and Ahmad (1983) and mineralogy of Vertisols by Dixon (1982). While the genesis of these soils has been considered simple and single-processed, it is more probable that they form under multiple genetic pathways considerably more complex than generally recognized (Blokuis, 1982).

The purpose of this paper is to review and evaluate currently held pedogenic models of Vertisols. Special consideration is given to sampling of Vertisols, cambic horizon development, shrink-swell phenomena, and microfabric inferences of pedogenesis.

PEDOGENIC MODELS

Morphogenetic markers

The pedogenesis of Vertisols must consider those properties that are common to this soil order. These include: minimal horizon differentiation, high clay content, high specific surface area, high CEC, low organic matter content in spite of usual dark pigmentation, high shrink-swell potential, extensive cracking upon drying, very plastic and sticky wet consistency, granular and angular blocky self-mulching surface horizons, wedge-shaped tilted platy parallel-pipeds in the subsoil, slickensides, and gilgai relief.

At the order level, the morphogenetic differentiae reflect soil instability, soil movement, and climatic bias. These differentiae are: mineral soils with no lithic or paralithic contact within 50 cm, cracks that are 1 cm wide and at least 50 cm deep, 30% or more clay in upper 50 cm, and one or more of the following: gilgai, slickensides that occur within 25 to 100 cm of the surface, or wedge-shaped aggregates at 10 to 60 degrees from the horizontal. Temperature regimes must be frigid or warmer. At the suborder level, the period and duration of cracking is the major criterion, while at the great group level, soil color is the major diagnostic property (Soil Survey Staff, 1975). Color bias of 1.5 chroma or greater for the Chrom great groups and <1.5 for the Pell great groups does not satisfactorily convey soil moisture regimes because color is often confounded with parent material lithology and geomorphic stability.

Pedoturbation model

Simply stated, the self-swallowing concept of Vertisols argues that when a clayey soil with a high shrink-swell potential dries, large cracks develop into which surficial and sidewall material is sloughed (Fig. 1). Upon rewetting, the cracks fill with water, swelling of entrained material and adjacent subsoil ensues, and a space problem is generated. Swelling pressures are relieved by oblique upward shifting of the subsoil to accommodate the space occupied by the infilled crack. This model holds that pedoturbation is sufficient to retard or obliterate pedogenic horizonation. According to proponents of this model, the churning activity and forces associated with it result in slickenside formation, gilgai microtopography, and wedge-shaped structural units commonly observed in these soils (Hilgard, 1906; Vageler and Alten, 1932; Beinroth, 1966; Hallsworth and Beckmann, 1969; Vester et al., 1973; Buol et al., 1980).

While pedoturbation in Vertisols is a dynamic process, it is an incomplete genetic concept and fails to adequately account for the following relationships and features:

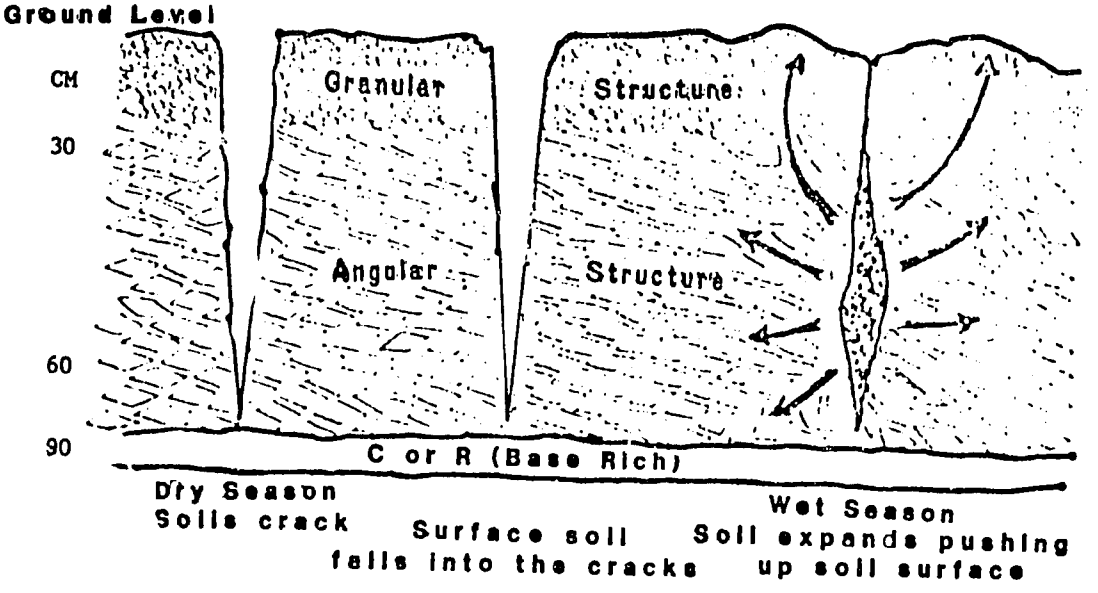


Fig. 1 - Pedoturbation or self-swallowing model of structure, slickenside and gilgai formation in Vertisols. (From Fig. 16.3, Buol, et al., 1980, page 235).

1. Systematic depth functions of organic matter, carbonates, and soluble salts (Wilding et al., 1980);

2. Systematic increasing depth functions for mean residence times of organic matter with depth similar to other soils not subject to cracking (Yaalon and Scharpenseel, 1972);

3. Maximum slickenside development below the depth of maximum seasonal cracking and the zone of maximum cracking infilling (Yaalon and Kalmar, 1978; El Aberdine et al., 1971);

4. Gilgai and structure formation more rapid (5 to < 200 years) than can be accounted for by the rate or total amount of crack infilling (Bremer, 1965; Yaalon and Kalmar, 1978; Parsons et al., 1973; White, 1967; and observations by the author).

The systematic depth functions of soil properties argue strongly that the rate of pedoturbation is not so rapid as to obliterate long-term translocation. If pedoturbation in the actively cracked zone were intense, one would expect constant depth functions in the mixxed zone followed by marked increases with depth. These relationships don't hold, but Yaalon and Scharpenseel (1972) did observe that the increase in mean residence time of organic matter with depth was slower for the Vertisols compared to Udolls and Udalfs, due probably to pedoturbation effects. Another complication to this model is that pressures generated by rewetting and swelling of the infilled crack material would likely be resolved by upward movement in the crack zone rather than oblique stresses. Lack of confining stresses from above reflect long hysteresis effects of crack closure near the soil surface. This would preclude development of extensive lateral stresses due to space readjustments for infilled material as illustrated by Buol (1980), (Fig.1).

Differential loading model

This theory offered by Paton (1974) suggests that gilgai forms by process of differential loading where clays move from areas of high confining pressure to areas of low confining pressure. Paton suggests that surface soils of unequal thickness and low plasticity exert differential pressure upon an underlying plastic subsoil or substratum. Analogies were drawn from sedimentary load structures and mudlump islands of the Mississippi delta (Morgan et al., 1968). In the latter, densely packed, water-saturated sands and silts overlie highly fluid muds. Under these conditions, the overlying, more dense sands and silts tend to sink in less dense muds. The muds move laterally and upwards towards areas of lower confining pressures. The driving mechanism results from large disparities in densities of the two materials (Gustavson, 1975).

The analogy of gilgai formation to sedimentary loading is questionable for the following reasons:

1. Marked density differences have not been observed between horizons or among gilgai elements in Vertisols (Gustavson, 1975).

2. Sedimentary loading structures have formed on depositional slopes, the structures tend to be elongated transverse to slope direction. Linear gilgai on steeper slopes have elongated ridges and troughs parallel to slope direction (Gustavson, 1975).

3. The required regularity of the gilgai pattern would not seem compatible with the processes causing density differences in sedimentary loading (Blokhuis, 1982).

Soil mechanics model

This model of Vertisol pedogenesis was first offered by Howard (1932) and amplified on by Yaalon and Kalmar (1978). It is not as well-known or accepted by pedologists but is held in vogue by civil engineers (Gustavson, 1975). Simply, it says that soil materials will fail along shear planes (slickensides) whenever the swelling pressures of a confined system exceed the shear strength of the soil (Yong and Warkentin, 1975; Yaalon and Kalmar, 1978; McCormack and Wilding, 1973). The shear strength of a soil is a function of cohesion plus the angle of internal friction. Cohesion is a function of bulk density, clay content, clay mineralogy, and moisture content (McCormack and Wilding, 1979), while the angle of internal friction is related to abundance, roughness, and interlocking of skeleton grains. Upon swelling, a soil is acted upon by two sets of stresses -- vertical and lateral (Fig. 2). When the vertical stresses are confined and lateral stresses exceed the shear strength of the soil, failure occurs along a grooved shear plane theoretically at 45° to the horizontal (Fig. 2). In practice such shear failure may range from 10° to 60° (Smart, 1970).

Consider a dry soil that is rewetting. The wetting front takes place downward from the self-mulching surface horizons and upward from lower solum via tapered cracks initially filled with water (Blake et al., 1973). Absorption of water, swelling, and expansion of the surficial horizons is relieved by upward movement of the surface. However, in the subsoil overburden pressures confine vertical movement and lateral swelling is resolved by crack closure and subsequent development of swelling pressures that exceed the soil shear strength. Swelling pressures in Vertisols are of the order of 1 to 5 kg/cm^2 (Komornik and Zeitlin, 1970; Gustavson, 1975) but shear strengths at moisture contents when failure is most probable are below 1 km^2/cm^2. Lateral swelling pressures may often exceed vertical swelling pressures by a factor of 4 or more (Yong and Warkentin, 1975; Komornik and Zeitlen, 1970).

Upon shearing, soil materials are translated along slickenside glide planes. Blokhuis (1982) and Ritchie et al. (1972) have suggested that slickensides near the base of the solum and along the wavy A-AC contact are continuous from an area below the center of the microlow towards a higher position below the center of the microhigh. This is also consistent with observations of White and Bonestell (1960). When observed in the third dimension, slickenside patterns of normal gilgai often form cones of revolution with the vertex centered in the microlow (Newman, 1982; field observations of the author, Fig. 3). It is postulated that along such oblique shear planes blocks of subsoil and substratum are upthrust and downthrown. A similar process may explain linear gilgai except the slickenside planes form a corrugated pattern parallel to the slope gradient.

It is speculated that slickenside patterns are related to major desiccation cracks that initially formed during seasonal dry periods in the parent material. For normal gilgai, cracks would form a polygonal network similar to those currently found in microlows. Upon rewetting and swelling, oblique

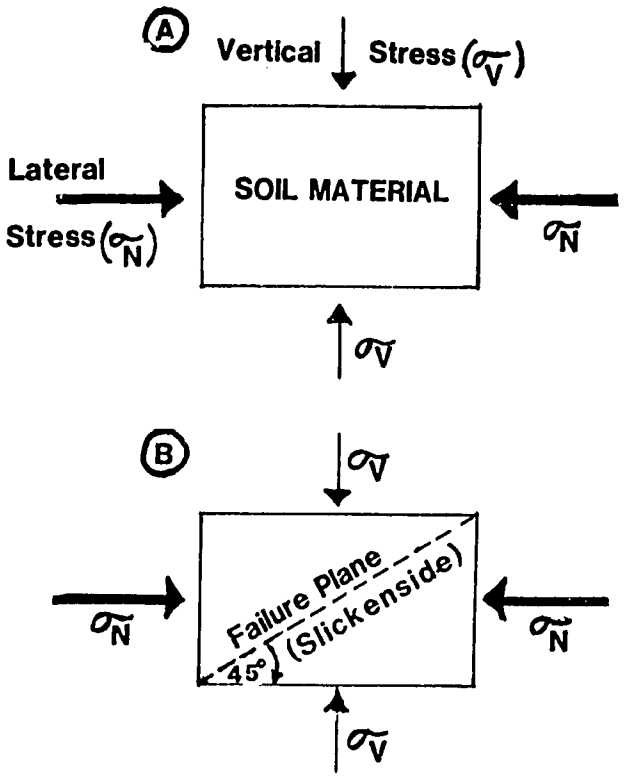


Fig. 2 - Soil mechanics model of slickenside formation when confining stresses exceed soil shear strength: (A) Vertical and horizontal stresses acting on a soil ped, and (B) Orientation of shear plane at 45° to the principal stress. (Size of vectors proportional to stress magnitude).

slickensides would form inclined to the direction of major principal stress (lateral); soil material would be translated along these planes. Once initiated, a slightly undulating topography would result and leaching potential would be enhanced in microlows along major and minor desiccation cracks. Leachates would move downward until intercepted by oblique slickenside planes. Then most of the flow would be diverted and effectively funnel to the microlow. Both the topographic relief and slickenside pattern favor development and leaching of microlows while microhighs are renewal sites for subsoil and parent material. Once microrelief is established, desiccation cracks will be best expressed in microlows because they have the highest noncarbonate clay content, undergo the greatest differential in moisture content, and have the highest shrink-swell potential (Blokhuis, 1982).

It is postulated that coarse-textured, recent overburden mantling clayey subsoils will decrease slickenside activity and gilgai formation. Such a mantle will effectively serve as a "dust" mulch in breaking the micropore continuity, decrease evaporative potential and decrease subsoil moisture oscillations that give rise to maximum shrink-swell potentials. This may partially explain the absence of gilgai relief in ash-mantled landscapes of central El Salvador in spite of evident slickensides in subsoils. Alternatively or complementarily, the infrequent number of wet-dry cycles in this seasonally wet-dry climate may hinder gilgai formation.

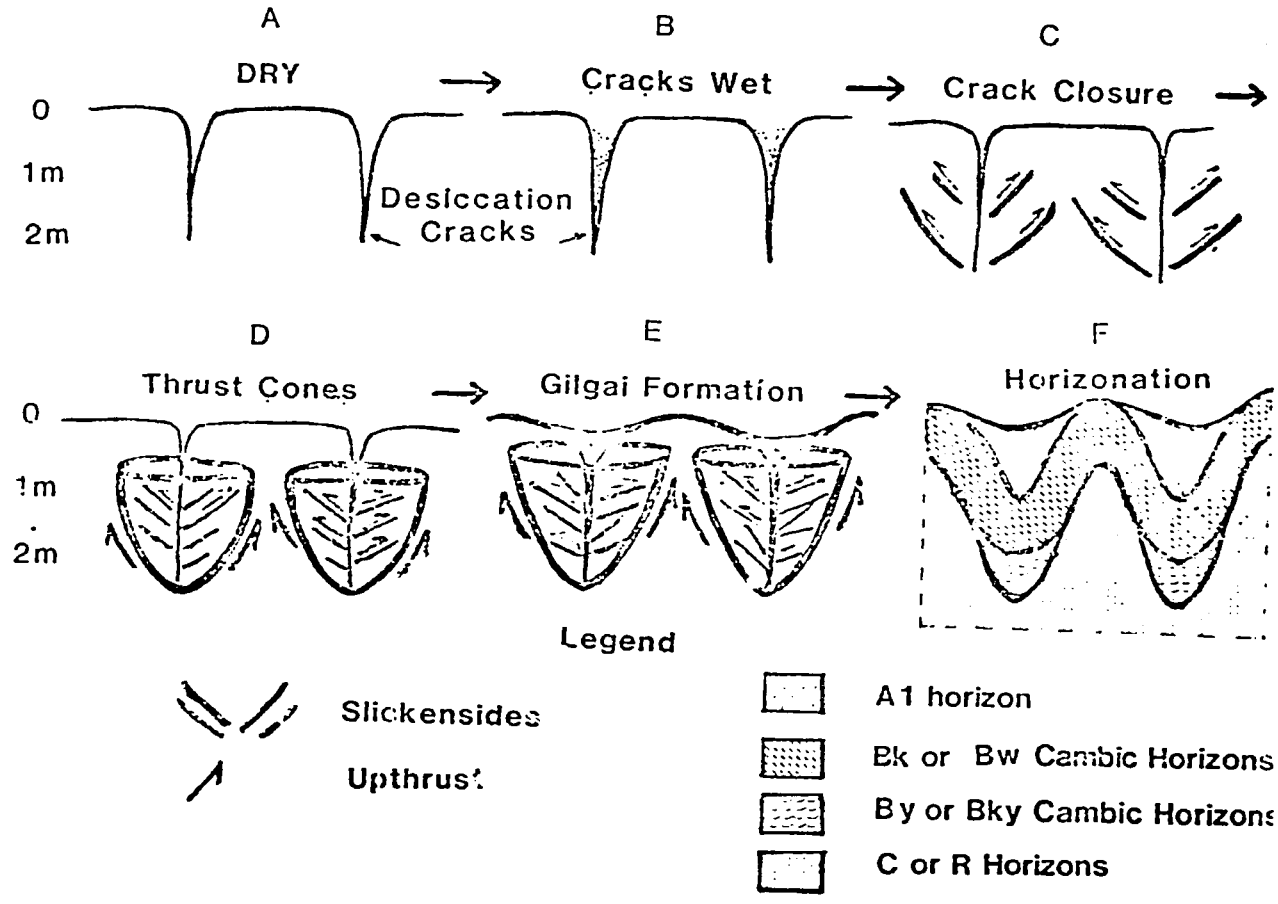
In summary, the proposed stages of gilgai formation are schematically illustrated in Fig. 3. This model accommodates the rapid formation of slickensides, pedogenic structure, and gilgai relief. It is compatible with systematic depth functions commonly observed in Vertisols and differential intensities of development between microhighs versus microlows (discussed later). Further, it recognizes pedoturbation as a long-term process but one which is not sufficiently dynamic to obliterate the above Vertisol properties.

SAMPLING OF VERTISOLS

Soil Taxonomy (Soil Survey Staff, 1975) states that the sampling unit is the pedon and the unit of classification is the polypedon. The pedon ranges from 1 to 10 m^2 in area or 1 to 3½ m in length depending on whether soil formation and composition are uniform spatially. In most cases Vertisols would occupy the larger of these variable dimensions and include one-half the gilgai cycle comprised of microhighs and microlows.

A variable-dimension pedon generates a problem in defining the sampling unit for Vertisols. Should the sampling unit be the microhigh, the microlow, the midrange between these two components, or the entire area represented by one-half the cycle? In practice, it is common to sample the microlow and describe horizon thickness and topography within the cyclic pedon. This does not foster a pedogenic understanding of properties or behavior between the cyclic components and skews our concept of Vertisols to those properties measured in microlows. For these reasons it is proposed that the pedon be defined by a constant area of 1 m^2. Vertisols with cyclic or intermittent horizonation would have one pedon sampled at the center of a microhigh and one pedon sampled representative of the microlow. For those lacking such topographic or compositional irregularity the pedon would be the same as for soils that now have uniform horizonation.

Fig. 3 - Schematic illustration of possible stages (A-F) in the formation of slickensides, gilgai and pedogenic horizonation.



Applying the above pedon concepts, spatial variability within a 1 m^2 area of a Houston Black series (Udic Pellustert) microlow is illustrated in Fig. 4. The CV's for saturation extractable cations and anions indicate that most soluble salts have CV's of the order of 10 to 20% except Na and SAR which are about 5%. For exchangeable properties (i.e. Na, CEC, ESP), pH and $CaCO_3$ equivalent to the CV's range from 5 to 10%. These results indicate that sampling four lateral subsamples within a 1 m^2 area for horizons of interest would permit mean estimates of chemical parameters of Vertisols within probable errors of 5 to 10% for most soil properties using an 80% confidence interval.

Differences in depth functions for OC, EC, extractable Na and calcium carbonate equivalent between microlow and microhigh pedons are illustrated for Houston Black series Fig. 5. These depth functions demonstrate that microlows have: (i) greater depths of carbonate leaching; (ii) lower calcium carbonate contents; (iii) greater depths of OC accumulation; and (iv) higher soluble and extractable salts. To understand the genesis of these soils, gilgai elements should be sampled separately. They have different properties and horizonation (Fig. 3).

CAMBIC HORIZON DEVELOPMENT

By convention, and sometimes with little morphological evidence, subsoil horizons in Vertisols have been designated AC to denote physical mixing of these two horizons. Pedoturbation was believed to be so dynamic that cambic horizons were precluded. This in spite of well-documented depth functions for OC, carbonate and soluble salt translocations and subsequent accumulations as illustrated in Fig. 5. Further, pedogenic formation of compound prismatic-blocky structure in subsoils is characteristic of cambic horizons. For the above reasons, it is fully appropriate to use horizon symbols that connote cambic horizon pedogenesis including Bw, By, Bk, Bz, BCk, BCy, etc. as justified.

Pedogenic carbonates in Vertisols occur as soft, diffuse and indurated channel infillings, nodules and cutans throughout the solum or in lower Bk and/or BCk horizons (Blokhuis et al., 1968; 1969). Translocation of gypsum and soluble salts occur to depths at or just above maximum accumulation of carbonates; such salts are commonly immobilized in lower BC horizons or at the contact with less permeable C horizons (Fig. 5). More intensive translocation of carbonates and salts occur in microlows than microhighs, probably as a consequence of greater volumes of water entrapped and leached through microlows. Below surficial horizons, subsoils of microlows contain about 1/2 to 2/3 the carbonate contents of microhighs. Strong evidence for dissolution and loss of carbonates occurs in microlows compared to paired microhighs (Fig. 5, and Yule and Ritchie, 1980).

Systematic translocations of OC occur to depths of near 2 m, especially in microlows. This distribution is not indicative of a depth function primarily attributed to pedoturbation. Distributions of organic matter are too regular and too deep to be accounted for by this process. Apparently dark pigmentation in these soils accompanied by low organic matter levels is a consequence of clay-organic complexes bonded primarily to exterior clay surfaces (Dixon, 1982).

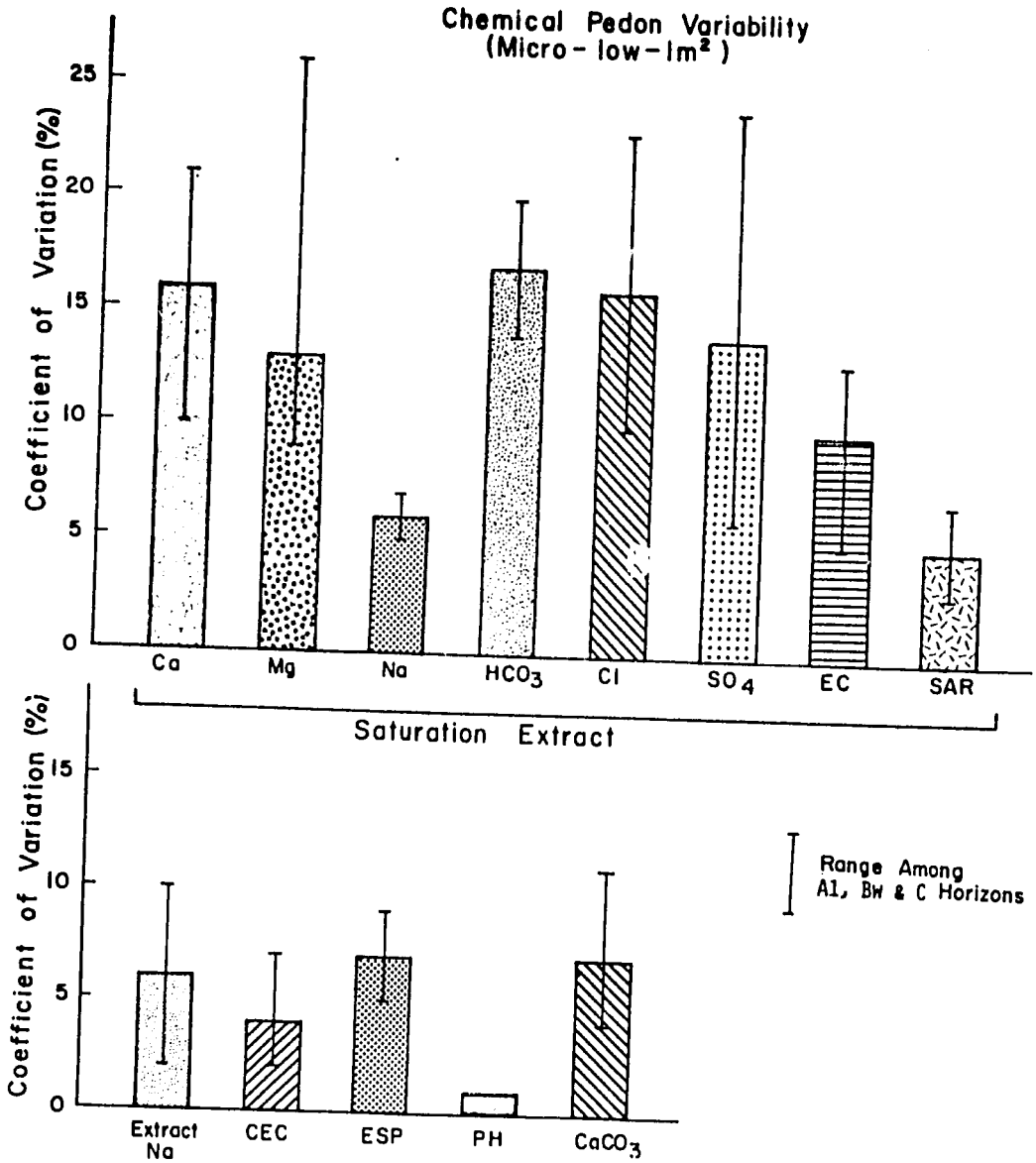


Fig. 4 - Observed chemical variability within a sampling unit of 1 m^2 for Houston Black (Udic Pellustert) microlow gilgai element.

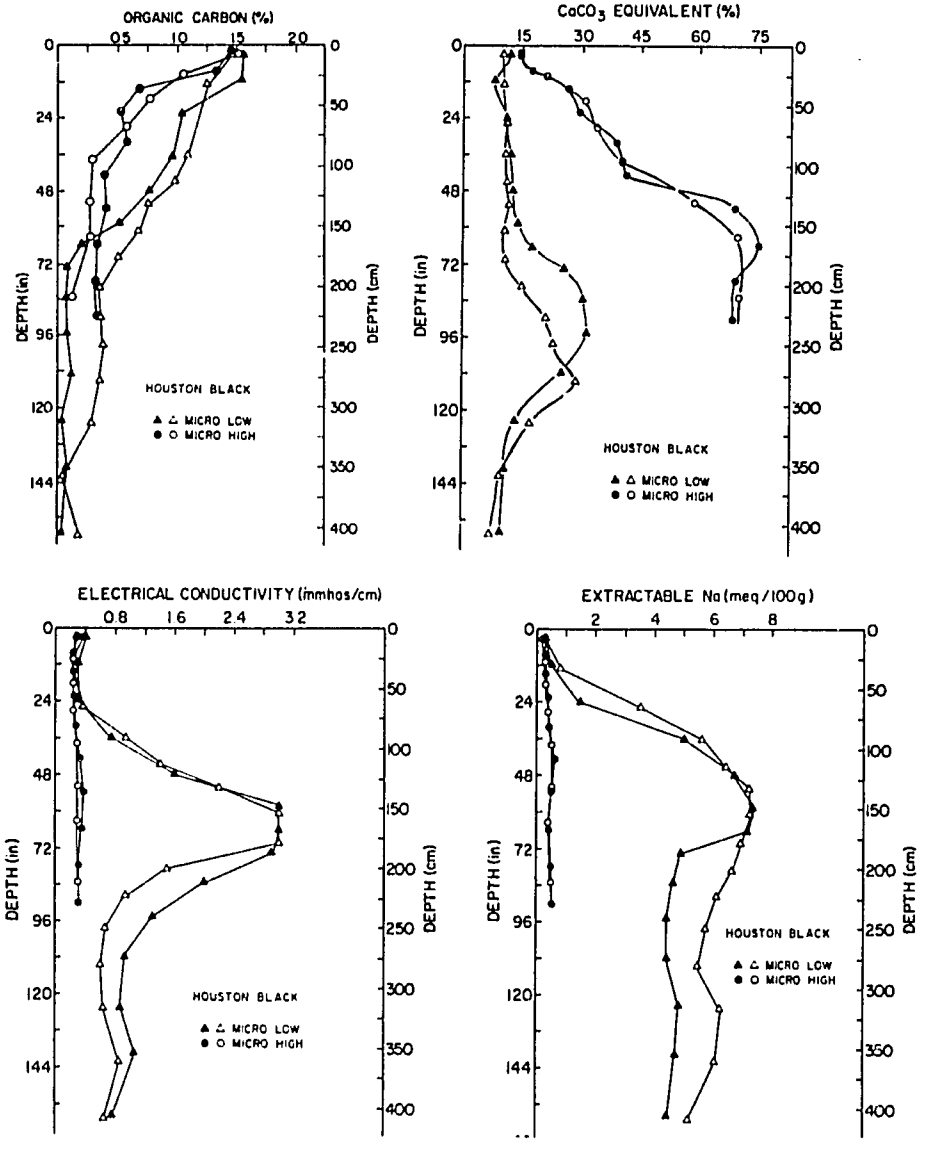


Fig. 5 - Depth functions for organic carbon, $CaCO_3$ equivalent, extractable Na, and electrical conductivity for microlow versus microhigh gilgai elements of a Houston Black (Udic Pellustert).

SHRINK-SWELL PHENOMENA

Clay mineral influences

Vertisols are noted for their high clay contents, high shrink-swell potentials (COLE values from 0.10 to 0.20 or higher) and smectitic or other expandable 2:1 layer clay mineral systems (Dixon, 1982). High clay contents are either inherited from the parent sediment or rapidly formed from labile mafic pyroclastic, igneous or metamorphic rocks. The formation and stability of smectitic clays in Vertisols has generally been attributed to base-rich environments, but Dixon (1982) suggests that dissolved silica may play an important role.

A common misnomer is that marked volume changes are due to hydration or dehydration of the clay interlayers (lamallae). Green-Kelly (1974) concluded that interparticle rather than interlamallar shrinkage was the principal component of bulk shrinkage. Because swelling of clay plasma aggregates (quasi-crystals) is complete at low water potentials (< - 20 bars, Norrish, 1954), observed field volume changes must occur outside the plasma aggregates (Yule and Ritchie, 1980). According to Yule and Ritchie (1980), shrinkage in Vertisols is normal, equidimensional and linear over the range from residual water loss (below the shrinkage limit) up to structural water loss (above the swelling limit).

It is not the clay mineralogy that dictates soil shrink-swell potential but rather the amount of external surface area associated with plasma aggregates or individual clay domains. The high shrink-swell potential of smectites is due to their natural occurrence in fine-grained clays. Kaolinitic or other clay mineral suites could generate equally high shrink-swell attributes if they occurred in fine grain sizes, but this is usually not the case. For these reasons, Vertisols with a wide range of clay suites are possible but smectitic mineralogy is most probable.

Microfabric inferences

The shrink-swell attributes of Vertisols are known to strongly control the width, depth, and periodicity of cracking (Blokhuis, 1982). Cracking in turn controls the water recharge which results in differential swelling within the soil matrix. Forces associated with swelling give rise to structural attributes of these soils, pressure faces on ped surfaces, and slickensides, all of which are observed in microfabrics.

Microfabrics of Vertisols reflect microshear phenomena and are manifest by vosepic, skelsepic, masepic, lattisepic, or some combination of the above. Blokhuis (1982) indicates a number of authors have identified vosepic fabrics. These would likely reflect pressure faces or major slickenside surfaces caused by high lateral or vertical stresses. Commonly, this author has observed multiple sepic fabrics within the s-matrix indicative of differential wetting and swelling on a microscale (McCormack and Wilding, 1973). Fig. 6 suggests schematically how such microfabrics could form. Yaalon and Kalmar (1978) suggest irregular wetting and preferred swelling around sand grains producing upward directional migration. While evidence for this phenomenon has not been observed from textural depth functions of Vertisols in Texas, skelsepic microfabrics likely reflect differential swelling and particle rotation in

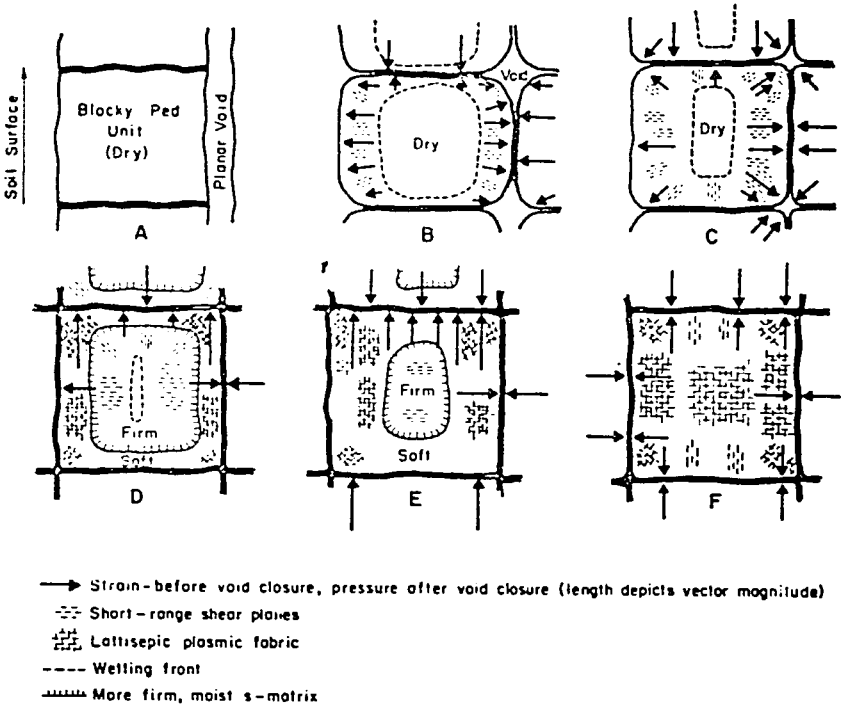


Fig. 6 - Schematic illustration of proposed origin for stress oriented plasmic fabrics found within structural units of Vertisols. Microshear generates masepic, skelsepic and lattisepic plasmic fabrics. (Taken from Fig. 5, McCormack and Wilding, 1973).

close proximity to skeleton grains. In calcareous Torrerts of southwest Texas, the major plasmic fabric is crystic because of the abundance of fine-grained calcite.

Argillic horizons or evidence of clay translocation are seldom observed in Vertisols. Dispersion of clays is not favored by their Ca and Mg saturation, presence of carbonates, or stable organic-clay interactions. Further, subsoil ped surfaces are too dynamic and unstable to serve as favorable sites for illuviation. However, Blokhuis (1982) has cited several reports of clay translocation in Vertisols and in a recent study of Usterts formed from andesite in El Salvador a well-expressed argillic horizon with ferriargillans occurs below the major zone of pedoturbation and slickenside activity. Formation of an argillic horizon in such Vertisols is the precursor to formation of the physically active-cambic horizons which have incorporated the argillans and papules in the s-matrix.

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VERTISOLS IN THE COLLECTION OF THE INTERNATIONAL SOIL MUSEUM AND SOME SUGGESTIONS ON CLASSIFICATION

J.H.V. van Baren and W.G. Sombroek

ABSTRACT

This contribution contains descriptions and analytical data of eighteen Vertisols belonging to the collection of the International Soil Museum (ISM) at Wageningen, the Netherlands. It also gives some suggestions and discussion points on their classification in Soil Taxonomy and FAO-Unesco Soil Map of the World legend.

MATERIALS AND METHODS

Over the years, ISM collected nearly 20 Vertisol profiles and about 10 soils with vertic properties. Of these, 17 Vertisols have been analyzed with standard methods. The description of site and soil and the analytical data are given in an Appendix, available upon request from ISM. The analytical data have varying degrees of completeness, with COLE data lacking in particular. In fact, the collection awaits enlargement with profiles from Sudan, USA, Argentine, Venezuela, and Kenya. Then a systematic comparative study can be undertaken by any future guest researcher at ISM.

The following soils are comprised in this contribution:

Country and Soil Code		FAO-Unesco Legend	USDA Soil Taxonomy
Australia	AUS4	Chromic Vertisol	Udorthentic Chromustert, fixed, mixed (?), thermic
	AUS5	Chromic Vertisol	Typic Chromoxerert, very fine, mixed, thermic
	AUS6	Pellic Vertisol	Typic Pelludert, fine, montmorillonitic, thermic
Botswana	RB2	Pellic Vertisol	Typic Pellustert, fine, montmorillonitic/mixed, hyperthermic

Country and Soil Code		FAO-Unesco Legend	USDA Soil Taxonomy
Greece	GR1	Pellic Vertisol	Typic Pelloxerert, very fine, montmorillonitic, mesic
	GR6	Chromic Vertisol	Entic Chromoxerert, fine montmorillonitic, mesic
India	IND8	Chromic Vertisol	Typic Chromustert, fine montmorillonitic, hyperthermic
Italy	I13	Chromic Vertisol	Aquic Chromoxerert, very fine, mixed, mesic
Namibia	SWA9	Pellic Vertisol	Typic Pellustert, fine, mixed, hyperthermic
South Africa	ZA8	Pellic Vertisol	Udic Pellustert, fine, montmorillonitic, thermic
	ZA9	Chromic Vertisol	Typic (udic?) Chromustert, very fine, montmorillonitic, thermic
Spain	E3	Chromic Vertisol	Typic Chromoxerert, fine, montmorillonitic, thermic
	E12	Chromic Vertisol	Typio Chromoxerert, fine, montmorillonitic, thermic
	E18	Chromic Vertisol	Typic Chromoxerert, fine, montmorillonitic, thermic
Thailand	T2	Pellic Vertisol	Udic Pellustert, fine, montmorillonitic, isohyperthermic
Turkey	TR14	Pellic Vertisol	Typic Pelloxerert, fine, montmorillonitic, mesic
Uruguay	URU2a 2b	Pellic Vertisol	Typic Pelludert, fine, montmorillonitic, thermic

The Uruguayan example is of special interest. It is a double profile because of outspoken gilgai features. Gently undulating uplands are concerned with a microrelief of gilgai in a wavy, linear pattern, forming a feather or fingerprint-like pattern on aerial photographs. The horizontal distance between the tops of the waves varies from four to eight meters and there is a striking difference in soil development on top of the waves and between them. In the first case, the very dark grey to black A1 (A11 to A15) extends to about 100 cm depth; in the second case, it is only about 20-30 cm thick. In both cases, the A1 is underlain by a thin ACck grading into a Cck (Kaplan and Ponce de León, 1981).

Rather than characterizing the mapping unit concerned by two taxonomic soil units, i.e. Typic Pelludert and Rendoll (?), the Urugayan soil scientists prefer to consider it as one (poly)pedon, called deep phase and shallow phase of a "ruptic" Vertisol ("ruptic" not for vertically abrupt transition but for horizontally discontinuous; cf. Altamirano et al., 1976). In contrast, the Vertisols without "double-profile" are called "haplic" Vertisols. In the deep phase of the ruptic Vertisols, there is evidence of clay translocation, which is confirmed by micromorphology. An A-Bt-C(ck) horizon sequence is found; hence, a local classification of "luvic" (and ruptic) Vertisols is applied.

DISCUSSION

The relatively small number of profiles did not allow general statements on the classification of Vertisols. Some specific points for discussion (partly based on the observations and data of the ISM soil monolith collection) are, however, mentioned below:[1]

1. It may be useful to give a special name and code to the subsurface horizon of Vertisols (and vertic subgroups of other soils). Such a horizon would have a well-developed prismatic structure, pronounced slickensides, a minimum percentage of clay and montmorillonitic or at least mixed clay mineralogy.

For one, such a denomination would avoid the awkward multiple subdivisions of the Al c.q. the Ac horizons found in many Vertisol profile descriptions. One may then speak of a "vertic horizon," with the coding P (for Pelosol - Kubiëna/Mückenhausen) or better even the coding V (for Verton - FitzPatrick). Reference is made to the paper of McGarity (this Workshop) which also proposes to use V.

A denomination such as Bw (applied nowadays in the USA, or as Bv or (B)v as applied in Germany), would seem to be less appropriate because it concerns not a horizon of "weathering," but one of structural development.

2. The classification of Vertisols on account of the presence of gilgai, intersecting slickensides, and wedge-shaped or parallelepiped structural aggregates needs a quantitative definition of these phenomena. Additionally or alternatively, COLE value limits may be applied. Specifically, minimal requirements should be established to distinguish Vertisols proper from soils of Vertic subgroups.

3. The present subdivision of the Vertisols at suborder level into Torrerts, Xererts, Usterts, and Uderts--with definitions mainly related to a different duration of cracking over the year, rather than to the soil moisture regime within the peds--is very management-oriented and at times awkward once irrigation is practiced. The influence of different climatic environments on soil characteristics might be better defined on the depth of occurrence of free carbonates (lime and/or gypsum). The subdivision

[1]Written largely before ICOMERT's circular letter no. 2 became available (Comerma, 1982), hence, partly overlapping.

concerned may then be relegated to a lower categoric level and the carbonates criterion may be complemented with clay mineralogical and base-saturation criteria; Vertisols in some of the old, filled-in river valleys ("dambos") of the Eastern-African peneplains may have relatively low CEC-clay values, i.e. below 40 meq/100 g and they may be acid as well.

4. On the other hand, there may be a case for distinguishing Aquerts, notably for Vertisols in river plains with a shallow phreatic level in the dry season. It is doubtful whether the distinction can be made on color criteria alone (although such soils tend to have dark grey rather than very dark greyish-brown horizons). Quantifying the minimum duration of flooding or submergence c.q. shallowness and oscillation of the groundwater level may in such cases be a better proposition.

5. As mentioned in ICOMERT circular letter number 1 (Comerma, 1981) the present definitions of "Chromic" and "Pellic" do not result in a satisfactory subdivision between the Vertisols in a position of free external drainage (those on sloping terrains) and the Vertisols in a position without external drainage (those on flat terrains, but without flooding or shallow groundwater level).

The erstwhile differentiation between "lithomorphic" versus "topomorphic" Vertisols (as for instance used for the CTCA soil map of Africa (D'Hoore, 1964)), was straightforward and useful for mapping purposes; and an effort may be made to reintroduce it, possibly at suborder level.

6. There are quite a few Vertisol-like soils that have very thin (≤10 cm) topsoils of a massive and hard nature and relatively light texture over strongly cracking subsurface and subsoil horizons that conform to all criteria for Vertisols (abundance of slickensides, montmorillonitic clay minerals, little or no clay skins). Through plowing, the surface features concerned become temporarily obscured rather than obliterated; at drying out after the first postplowing rains the lighter, textured topsoil reassumes its massive nature. The soils occur, for instance, in parts of Kenya and in Uruguay, and have been called "minimal Planosols" at one time. For a part, they would fall under the "mazic" Vertisols of early approximations of Soil Taxonomy.

Rather than bury such soils in the multitude of taxa of the Alfisols or Inceptisols, one may want to bring to the fore the relationship with the "modal" Vertisols by allowing lower percentages of clay in the plowlayer than the present 30%. In general, "mazic" and "grumic" Vertisols should be reintroduced, for instance at the third level; the "tendency to resealing or hard-setting after cultivation" may well be measured quantitatively in the laboratory.

7. There may be a case to distinguish luvic Vertisols for the profiles with some degree of argilluviation, and ruptic Vertisols for the double-profile situations as reported by Uruguayan soil scientists. These distinctions can be made at a relatively low categoric level.

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RELATIONSHIPS BETWEEN VERTISOLS AND LENGTHS OF GROWING PERIOD IN THE DEVELOPING COUNTRIES

M.F. PURNELL

ABSTRACT

Using the classification of climate made for the FAO Agro-ecological Zones project and the World Soil Map as data base, the distribution of the Chromic and pellic Vertisols in zones with different lengths of growing periods is described. There are great differences between the five different continental regions covered, both in the proportions of Chromic and Pellic Vertisols and in the main climates in which they occur.

BACKGROUND

The objective of this paper is to provide some information on the global distribution of Vertisols in relation to climate.

The base data are provided by the FAO/Unesco Soil Map of the World (FAO, 1974) and the FAO Agro-ecological Zones (AEZ) project (FAO, 1978). Acknowledgement is made to Mr. G.M. Higgins for permission to use the AEZ data and to Ms. M. Zanetti for preparing the graphs.

The AEZ project was aimed at providing quantitative estimates of the extent and agricultural productivity of the arable lands of the world. For the climatic inventory a new system had to be developed, placing equal emphasis on temperature and on soil moisture, in order to compute the period when available water and temperature regime permit crop growth, i.e. the growing period. The growing period is defined as the continuous period (with high enough temperature) when rainfall exceeds half the potential evapotranspiration (calculated by the Penman method) plus the days required to use up an assumed 100 mm of stored soil moisture. A "normal" growing period has a humid phase, when rainfall exceeds potential evapotranspiration. "Intermediate" growing periods are recognized where rainfall is less than potential evapotranspiration but more than half of it (so plants can grow but under moisture stress).

Zones with equal lengths of growing period were mapped showing isolines at intervals of 30 days (from 90-120 days up to 340-365+ days), plus areas with no growing period, 0-75 days growing period and 75-90 days growing period. (See Table 1 for the list of growing period zones.)

Table 1.

AREAS OF VERTISOLS BY LENGTH OF GROWING PERIOD

('000 ha)

Length of Growing Period (days)	AFRICA			SOUTH AMERICA			CENTRAL AMERICA			SOUTHWEST ASIA			SOUTHEAST ASIA			DEVELOPING WORLD		
	V	Vc	Vp	V	Vc	Vp	V	Vc	Vp	V	Vc	Vp	V	Vc	Vp	V	Vc	Vp
0	1,322	225	4	-	-	115					43					1,322	268	119
1- 74	425	9,454	6,164	-	446	503	21	164	2,129	42	-			1,040		488	11,104	8,796
75- 89	74	3,343	1,950	-	353	100			291	-	-			2,916	746	74	6,612	3,087
90-119	204	3,898	3,207	18	348	138		2	540	36	234			7,450	2,530	258	11,932	6,415
120-149	774	3,950	6,417	1,251	219	2,401		66	1,451	2	531			16,601	1,971	2,027	21,367	12,240
150-179	1,700	12,851	9,285	1,167	174	389		219	3,003	6	1,948	264		10,940	2,871	2,873	26,132	15,812
180-209	1,914	6,143	5,864	528	381	2,264		184	1,534	1	695	43		4,297	1,966	2,443	11,700	11,671
210-239	606	940	2,485	506	685	834		43	1,499	6	298			285	519	1,118	2,251	5,337
240-269	161	806	2,135	1,059	338	427		66	1,139				7	209	1,101	1,227	1,419	4,802
270-299	71	268	1,358	305	674	1,884		117	725				13	223	563	389	1,282	4,530
300-329	2	8	296	14	336	4,463		30	192				116	261	562	132	635	5,513
330-364	1	-	296		395	1,758		3	106				-	96	57	1	494	2,217
365-		3	108		239	87							12	281	100	12	523	295
365+			487											56	29		56	516
Total	7,254	41,889	40,056	4,842	4,588	15,363	21	894	12,609	93	3,749	307	148	44,655	13,015	12,364	95,775	81,350

V = Undifferentiated Vertisols

Vc = Chromic Vertisols

Vp = Pellic Vertisols

The 0-90-day periods coincide well with the aridic moisture regime of Soil Taxonomy, and the dividing line between Ustic and Udic moisture regimes coincides in an approximate way with the 180-day growing period isoline.

By superimposing main climatic divisions, mainly based on temperature, and the growing period isolines on the Soil Map of the World, an original map of agro-ecological zones was produced. The acreage of each unit with similar soil and climate conditions was measured and stored in computer. The data can be retrieved by climatic zone, by soil, or by country.

This is a simplified account of the procedure which was, in fact, much more complicated to take into account annual variability and numerous special soil and climate constraints. The agro-ecological zones have been used in many different ways, especially in estimating constraint-free biomass production, yields of crops, population-supporting capacity, and technology transfer.

The base data can be used to show in which zones of growing periods the Vertisols occur. The Vertisols on the Soil Map of the World are in three main groups: the Chromic Vertisols with chroma more than 1.5, the Pellic Vertisols with chroma less than 1.5, and undifferentiated Vertisols. These groups coincide with the Chromu and Pellu groupings of Soil Taxonomy.

The AEZ project covered the developing countries, which are divided into five regions: Central America, South America, Africa, Southwest Asia, and Southeast Asia (for boundaries see FAO, 1978). It must be emphasized that North America, Europe, and the USSR, China, and Australia are not included, although they include extensive areas of Vertisols.

VERTISOL DISTRIBUTION

The total areas of the Vertisols in the different growing periods are shown in Fig. 1. There are two peaks of occurrence: in the 0-75-day growing period zone and around the 150-180-day zone. Few Vertisols occur in the wetter zones. There is also evidently a clear tendency for there to be a higher proportion of Chromic Vertisols in the drier climates and a much higher proportion of Pellic Vertisols in the wetter climates.

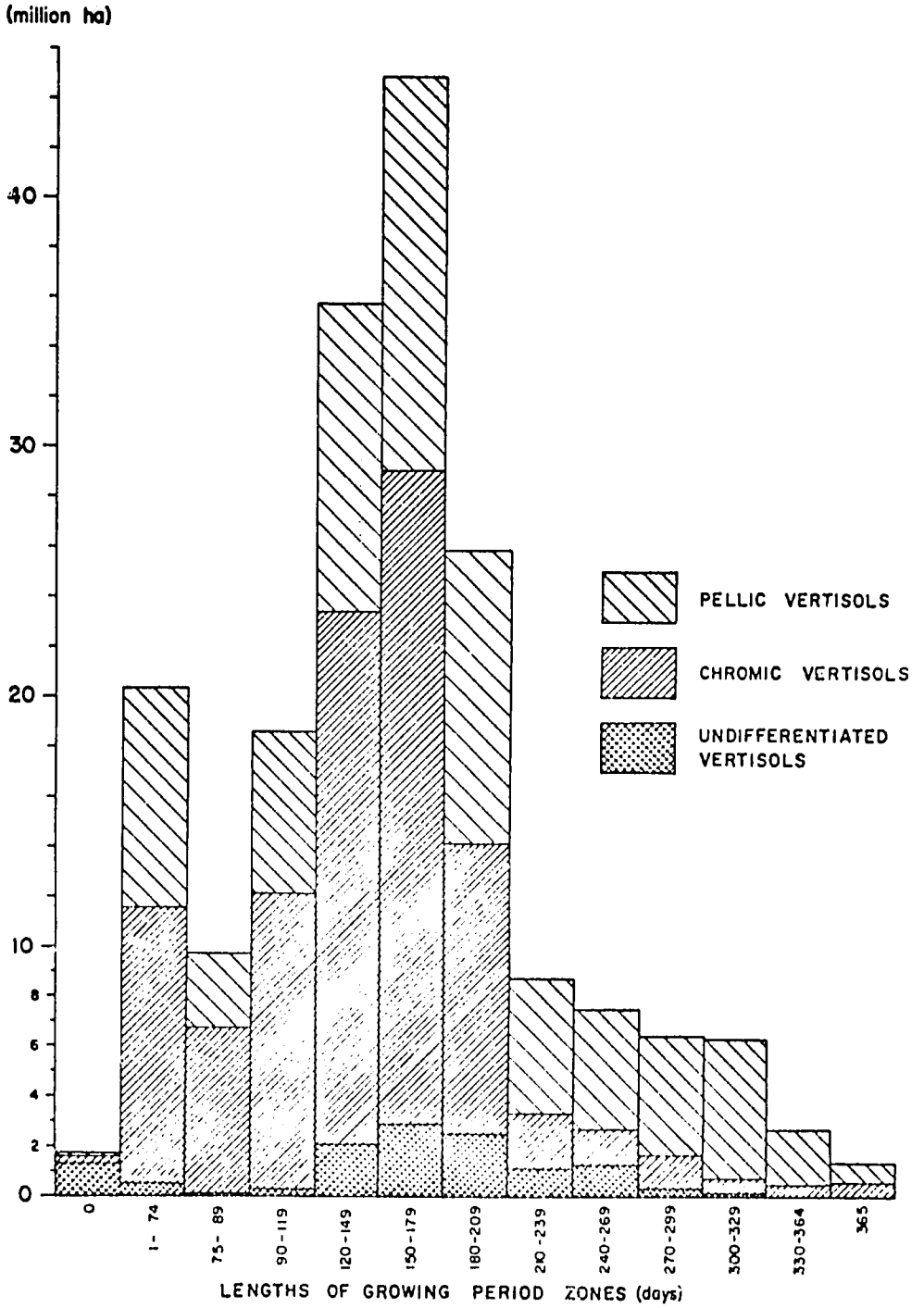
In Fig. 2 and Table 1, the distribution is shown for each of the five regions of the AEZ project.

In Africa, there are two peak areas of Vertisol occurrence: in the aridic climates and around the 180-210-day growing period. Both Chromic and Pellic Vertisols have similar distribution in relation to lengths of growing period. There are few Vertisols in the wetter areas.

In Southeast Asia, by contrast, there is only one peak of occurrence around the 120-150-day growing period. Most of the Vertisols are Chromic. It may be noted that the majority of the "Black cotton soils" of India, in fact, are Chromic rather than Pellic.

Fig. I

VERTISOLS AND LENGTHS OF GROWING PERIOD IN THE DEVELOPING COUNTRIES



In Southwest Asia, there are few Vertisols, and almost all are Chromic. They occur mostly in the 150-180 - day growing period, which is the wettest part of this dry region, and not in the dry areas.

In Central America, the distribution is similar to that in Africa, with some in the arid area and most in the 180-210 - day growing period. However, by contrast, most of the soils are Pellic with few Chromic Vertisols.

In South America, quite a different picture emerges. Most of the soils are Pellic and they occur mainly in the wetter areas with a peak in the 310-340 - day growing period. This is not altogether unexpected since much of the cocoa in such countries as Colombia and Nicaragua is grown on Vertisols, whereas in West Africa cocoa is not grown on Vertisols because they do not occur in the suitable climatic zone.

CONCLUSION

An explanation of the marked differences between the continents cannot be given at this time; detailed study would be needed.

It is evident that the Pellic and Chromic colors are rather weakly linked to climatic moisture conditions. However, topomorphic and lithomorphic effects are of equal or greater importance.

A degree of caution is appropriate in comparing experience from different continents, either for taxonomic classification or for management technology transfer, because the experience may not relate to the same suite of soils.

To avoid misunderstanding, it must be made clear that it is not suggested that growing period lengths should be used as the basis for a climatic classification of Vertisols or other soils. Experience with the development of the AEZ project is that it is an extremely complex matter to work out an agro-ecological climatic classification capable of predicting plant growth. The climatic regimes adopted in Soil Taxonomy should indicate the climatic conditions in the soil, such as rate of weathering and whether the soils are being leached weakly or strongly or not at all. This is indeed of importance for plant growth, but it is a secondary effect through the climatic influence on the soil. The inclusion of a climatic classification sufficiently detailed to make useful predictions of plant growth does not seem practicable within the confines of Soil Taxonomy.

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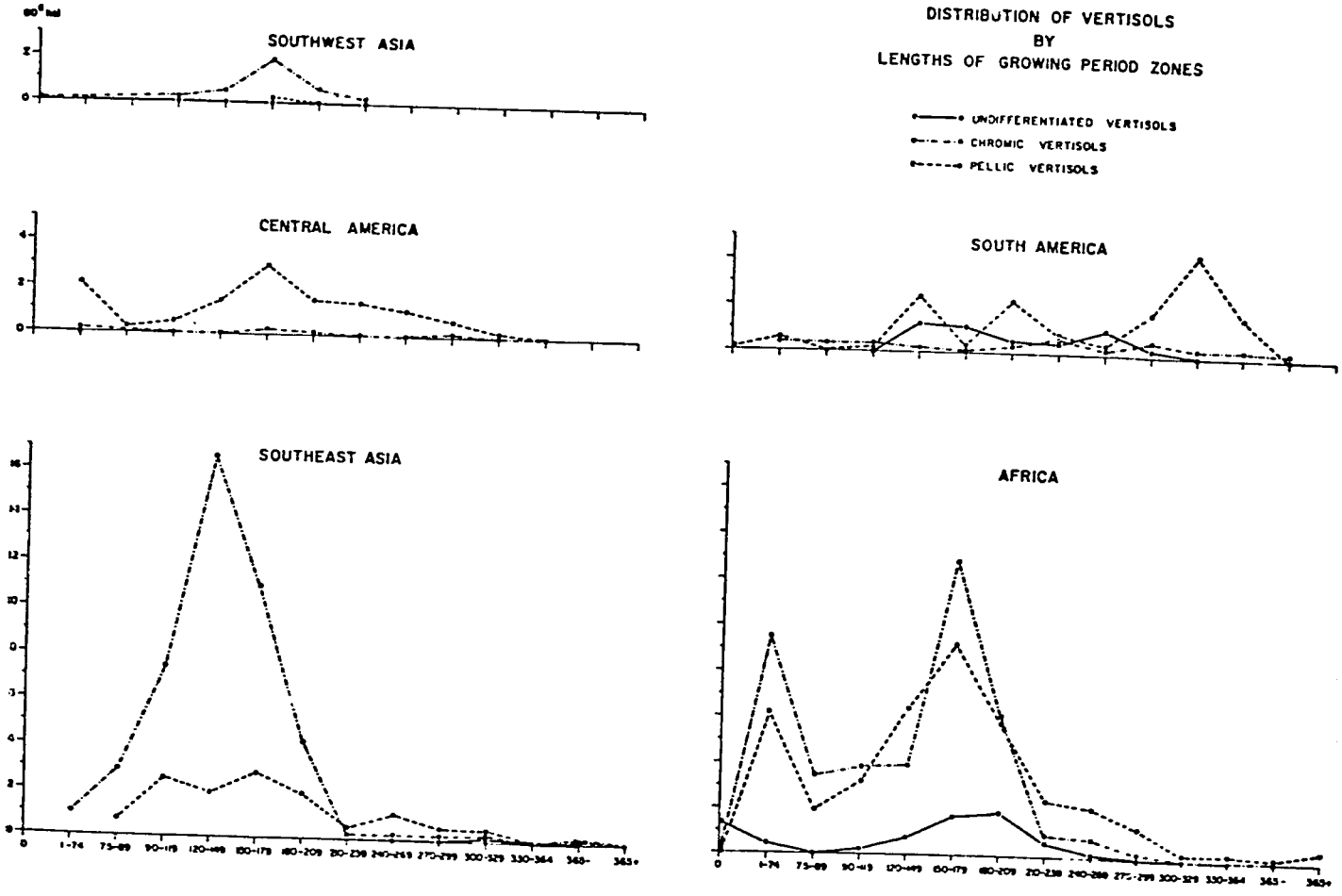
Fig. 2


DISTRIBUTION OF VERTISOLS
BY
LENGTHS OF GROWING PERIOD ZONES
UNDIFFERENTIATED VERTISOLS
CHROMIC VERTISOLS
PELLIC VERTISOLS
SOUTHWEST ASIA
CENTRAL AMERICA
SOUTH AMERICA
SOUTHEAST ASIA
AFRICA

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APPLICATION OF GEOSTATISTICS FOR SOIL SURVEY AND LAND EVALUATION[1]

B.B. Trangmar, U. Singh, R.S. Yost, and G. Uehara

ABSTRACT

Semi-variograms of exchangeable sodium percentage (ESP) show a spatial relationship between samples collected up to distances of 3.5-4.0 km apart on the Kenana sugar project, Sudan. Similar structure was retained in semi-variograms calculated from 100%, 75%, and 56% of the samples, but this was lost when 47% of the data were used.

The structural information contained in the semi-variograms was used to krige (estimate) ESP in a grid pattern across the project area. Little information was lost from the map of ESP kriged from 56% of the samples compared to the ESP map based on all the sample values. Estimation variance of kriged values increased only slightly using 56% of the samples compared to kriging based on all the samples. These results show that geostatistics can aid soil survey by obtaining similar results with fewer samples, provided an appropriate sampling scheme is used.

INTRODUCTION

The spatial variability of soil properties is an important factor in managing soils to obtain maximum crop productivity. The soil survey is one method of describing mappable variation in soil physical and chemical properties. The homogeneity of soil-mapping units is determined largely by the nature of the soil itself but is also influenced by the intensity and design of soil sampling and the scale of the final soil map.

In defining soil-mapping units, a range of values found within each unit can be specified for any given soil property. Such a measure of within unit variation gives no indication of how soil properties vary with distance between sample locations or the degree of similarity between adjacent samples. This makes it difficult to ascertain the efficiency of the particular sampling scheme used. In other words, could fewer samples located further apart have been just as effective in describing variation, or should samples have been collected closer together?

Users of soil surveys often estimate soil property values at unsampled locations by applying the mean value for the mapping unit bearing in mind the variance associated with that mean. However, the mean is calculated from a distribution of values and may not be a good estimator,

[1]Supported in part by Western Regional Project No. 155.

particularly if the variance is high or if the data are not normally distributed.

One approach that can be used in conjunction with soil surveys to improve sampling efficiency and estimation at unsampled locations is that of geostatistics (Burgess and Webster, 1980). The purpose of this paper is to illustrate how geostatistics could have been used to improve sampling efficiency of a soil survey of the Kenana sugar project (S.E. Extension), White Nile province, Sudan.

KENANA SUGAR PROJECT

The S.E. Extension of the Kenana sugar project is located between latitudes 12°26'N and 13°10'N and longitudes 33°00'E and 33°15'E covering 81,710 fedans (84,815 acres or 34,318 hectares). The soils were mapped on a scale of 1:50,000 by the Soil Survey Administration of the Sudan and are described as a large, homogeneous body of very fine, montmorillonitic, isohyperthermic, Typic Chromusterts (Adam, 1976). Although three soil-mapping units of the Dinder series are delineated, one mapping unit covers 98% of the project area. Soil parent material is Blue Nile alluvium, derived from weathering products of basic igneous and metamorphic rocks of the Abyssinian Plateau (Adam, 1976).

During the normal soil survey, auger samples were collected from depths of 0-25 and 75-100 cm at 254 sites located on a one-kilometer by one-kilometer grid (Fig. 1). Electrical conductivity, soluble sodium concentration of the saturation extract, pH, CEC, and exchangeable sodium and potassium were measured on all samples. The exchangeable sodium percentage (ESP) was also calculated. At 18 of the 254 sampling locations, a pit was excavated adjacent to the auger hole and sampled for full analysis of soil physical and chemical properties in order to classify the soils.

Exchangeable sodium percentage was found to be the soil property most affecting sugarcane yield and was used to assess the suitability of soils for irrigated sugarcane production (Adam, 1976). When ESP values for auger samples were compared to those from adjacent pits (Table 1), notable differences occurred in a number of sites, especially for subsoil samples. As noted in the soil survey report (Adam, 1976), such differences indicate that sodicity varies over short distances on a scale that cannot be shown by conventional soil maps. Similar short-range variation was observed for electrical conductivity. The 1 km square sampling grid used at Kenana suggests that interpolation based on the mean and variance of those samples is a function of a larger scale variation. Such interpolation does not adequately describe the short range or microvariation indicated in Table 1 because few samples were collected at short intervals.

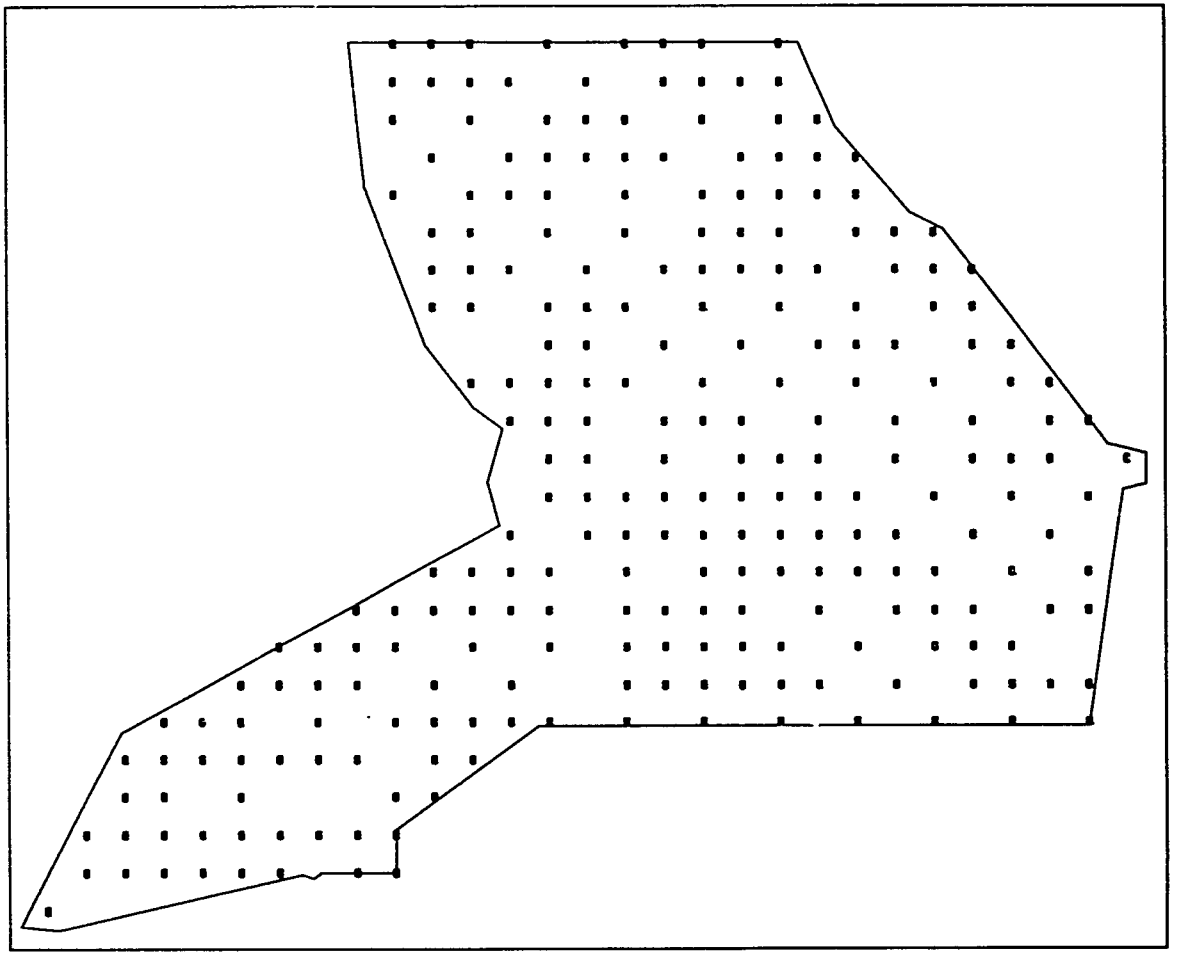

Figure 1. Location of soil sampling sites, Kenana Sugar Project.

Table 1. Comparison of exchangeable sodium percentage (0-25 cm soil depth) from adjacent pit and auger samples with kriged values for the same sites. Pit and auger values derived from Table 8, Adam, 1976.

Sample site	Pit	Auger	Kriged	Estimation Variance
KSPA 01	19.4	13	11.0	11.4
02	14	11	10.7	16.6
03	14.8	8	8.8	12.3
04	9	12	6.9	12.1
05	12	6	11.1	13.2
06	7.2	7	10.4	11.9
07	6.2	7	6.1	11.8
08	11.2	8	9.7	11.4
09	1	24	13.5	13.8
10	2	4	4.3	12.3
11	6.4	6	8.1	11.4
12	14.8	8	8.6	12.4
13	11.6	11	9.9	12.3
14	12.8	13	10.7	11.4
15	9.6	10	10.5	11.4
16	10.4	9	10.6	11.5
17	13	11	10.2	13.0
18	10	10	13.6	12.5

GEOSTATISTICS

Geostatistics are used to augment classical, statistical methods in analyzing spatial or temporal, random variables. Geostatistics are based on the concept that a sample value is expected to be affected by its position and its relationships with its neighbors. This means that samples collected close together should be more alike than samples collected further apart (David, 1977; Journel and Huijbregts, 1978; Clark, 1979).

In analyzing spatial variability, geostatistics can be used for optimal interpolation of values at any unsampled location. This is done by using the spatial dependence or change in variation of a measured property with distance between known sample sites.

THE SEMI-VARIOGRAM

In geostatistics, the semi-variance quantifies the spatial dependence of the variable. The semi-variance, $\gamma(h)$, is obtained by squaring the individual differences in sample values (z) between all pairs of locations (x) a given distance (h) apart and dividing this value by twice the number (N) of paired observations:

$$\text{i.e.} \qquad \gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} (z(x) - z(x + h))^2$$

The same computation can be repeated for all pairs of points any given distance apart.

A plot of semi-variance versus distance between sample pairs is called a "semi-variogram." The semi-variogram for 254 values of ESP for the Kenana sugar project is shown in Fig. 2. As distance between pairs increases, $\gamma(h)$ increases initially and then levels off toward an upper limit known as the "sill." The sill value is usually equivalent to the sample variance of classical statistics. Beyond the distance where $\gamma(h)$ approximates the sill value, the spatial dependence of sample values is essentially nil. This distance corresponds to the maximum range over which ESP values are spatially related. In Fig. 2, this distance is about 3.5 km.

A problem encountered in fitting a curve to the semi-variogram in Fig. 2 was that there were no samples collected at sites closer than 1 km. For Fig. 2 the zero intercept of the semi-variogram was estimated using data from Table 1. The auger and pit samples of Table 1 were collected adjacent to each other and can be considered to sample the same location in view of the larger 1 km spacing between all other samples. This means that for all practical purposes, the semi-variance computed from pairs in Table 1 may be treated as the zero intercept of the semi-variogram. Ideally, the semi-variance at locations zero distance apart should be zero. In Fig. 2, the semi-variance (6.15) at zero distance is 28% of the sample variance (sill) (21.6) and is caused by measurement errors or random occurrence of small pockets of high ESP.

A semi-variogram was then computed from 75% (192) of the sample values (Fig. 3). This number of values was obtained by deleting every third row of data points in the grid except those on the boundary (Fig. 4). The sill or sample variance of the semi-variogram was increased to 22.1 by withdrawing 25% of the sample values.

The sample size was further reduced to 56% (143) of the original by deleting every third row and column from the data base with the exception of border points (Fig. 5). The resulting pattern preserves the minimum distance between samples for a sufficient number of sample pairs to generate a useful semi-variogram. This pattern also allows the testing of anisotropy of the soil properties. The semi-variogram based on 56% of the measured ESP values was less clearly defined (Fig. 6) than those for 100% and 75% of the data. The sill value or sample variance increased to 24.0.

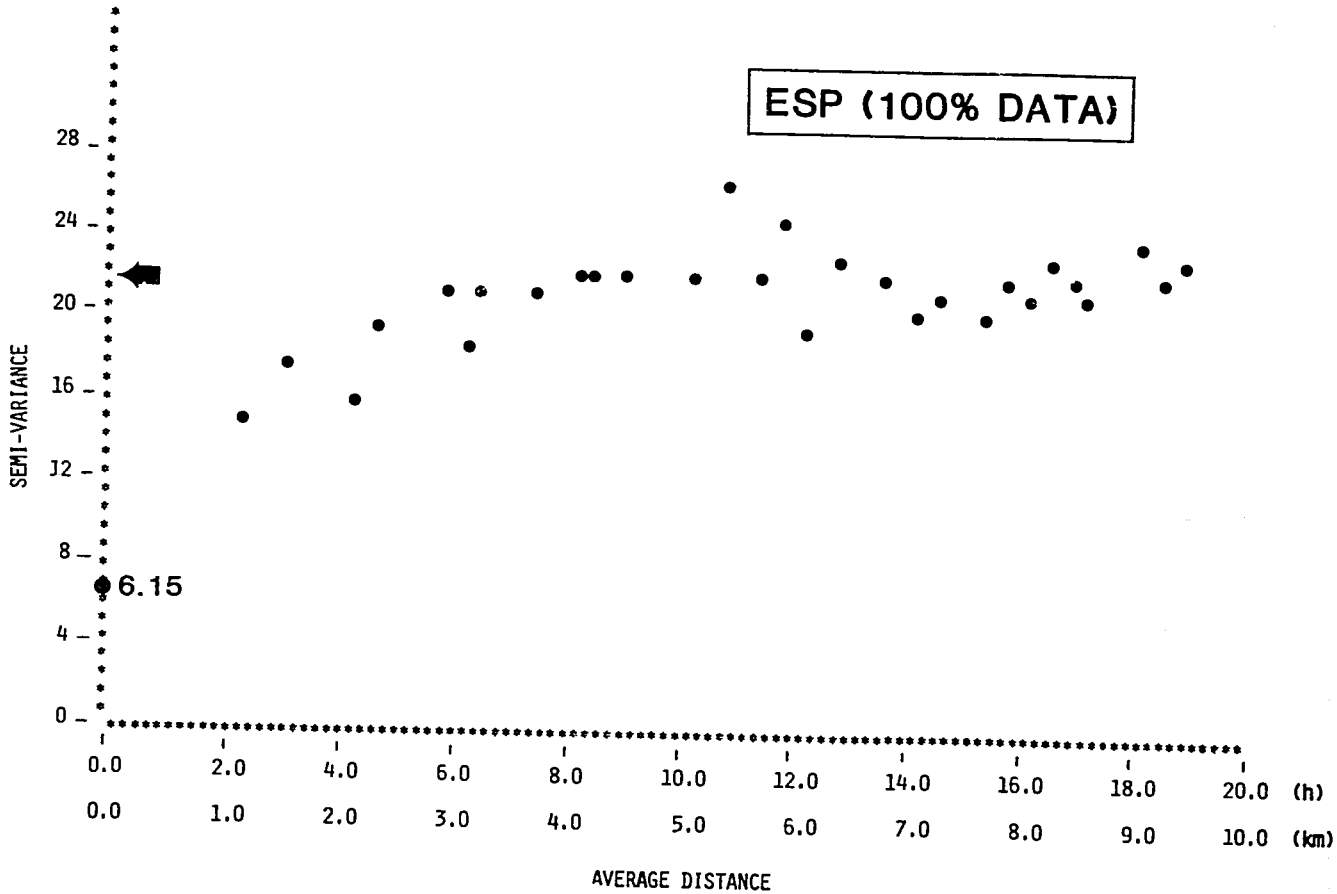

Figure 2. Semi-variogram for ESP determined from 100% (254) of samples.

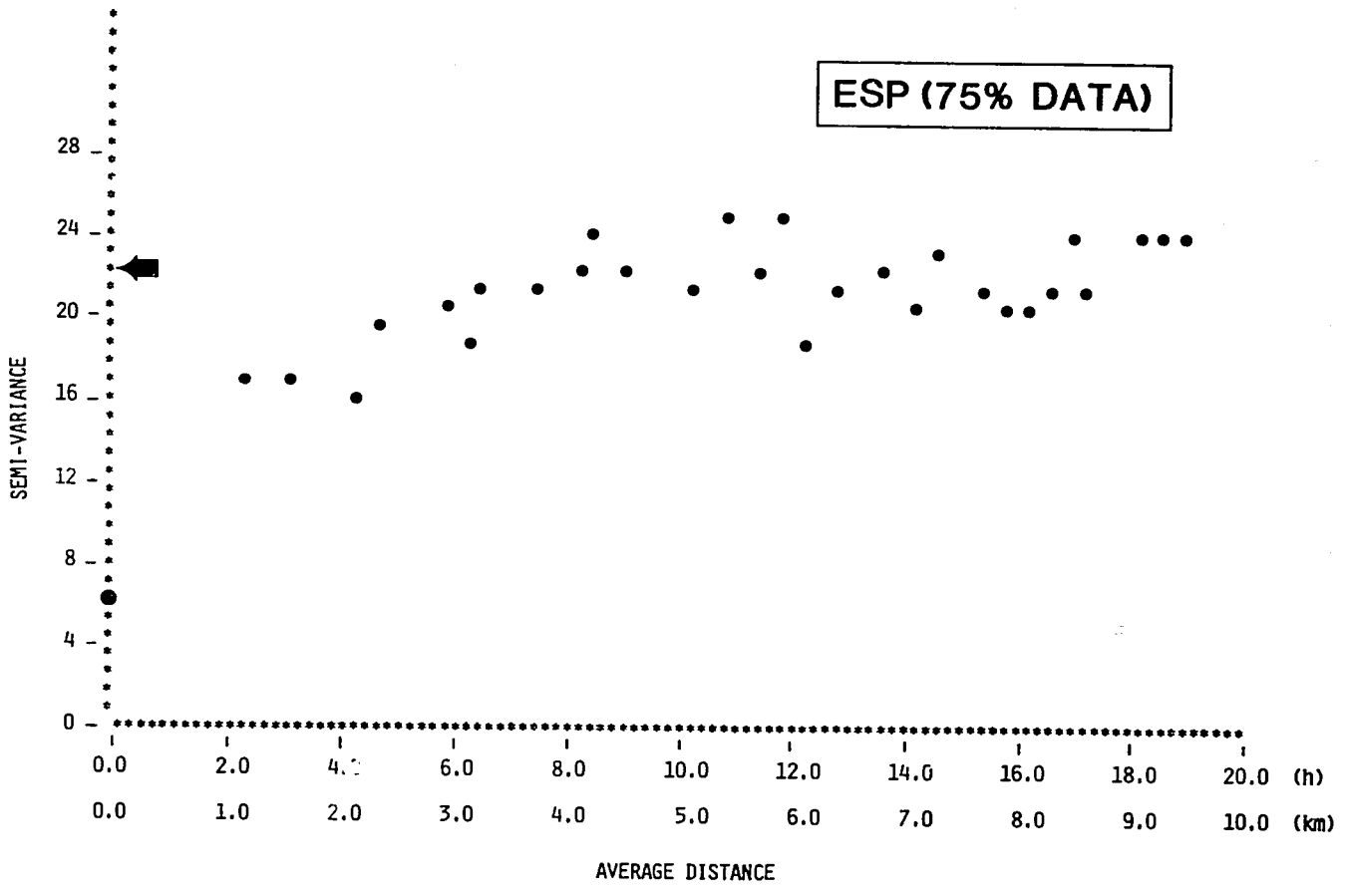

Figure 3. Semi-variogram for ESP determined from 75% (192) of samples.

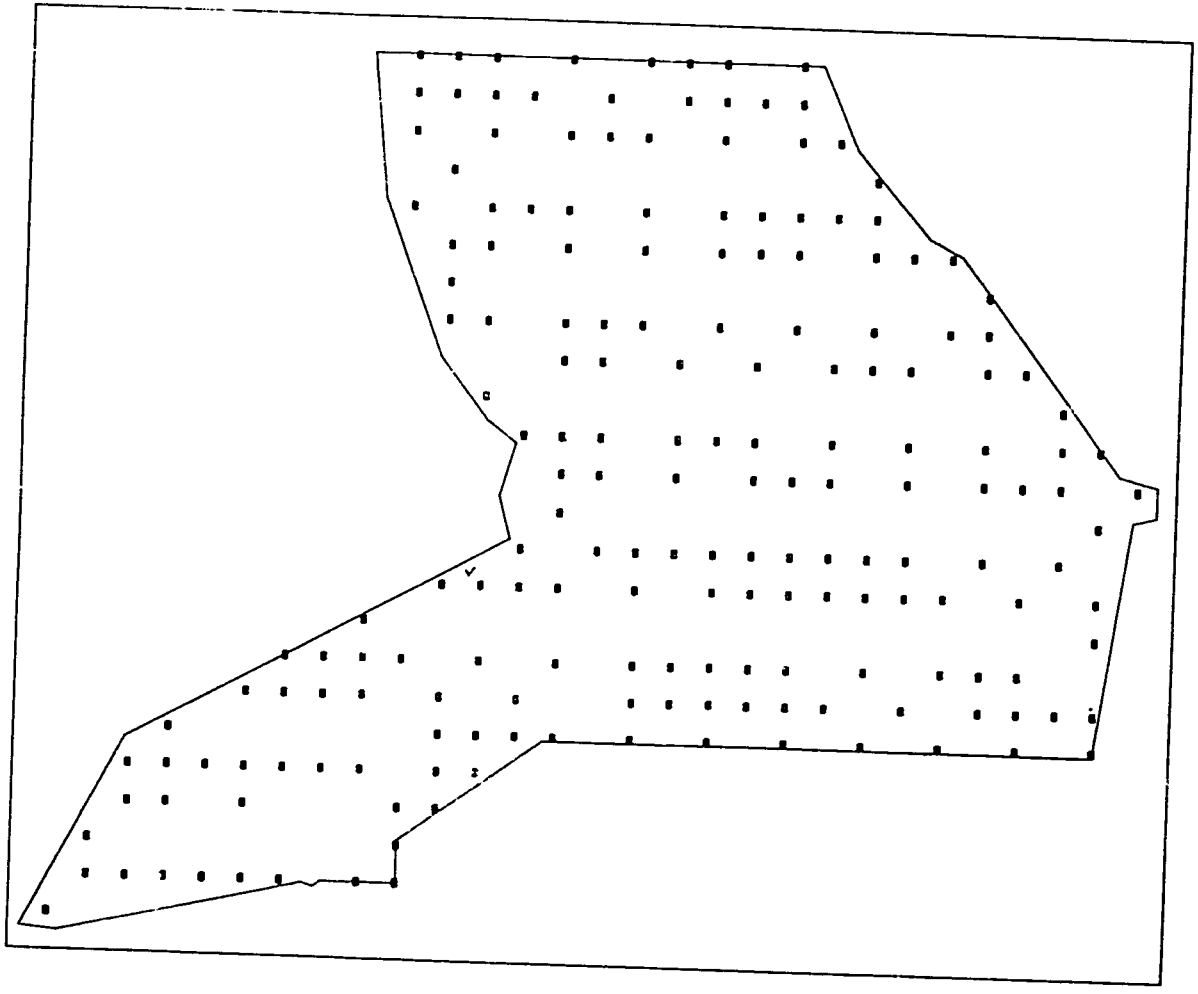

Figure 4. Location of sampling sites for calculations based on 75% of data collected.

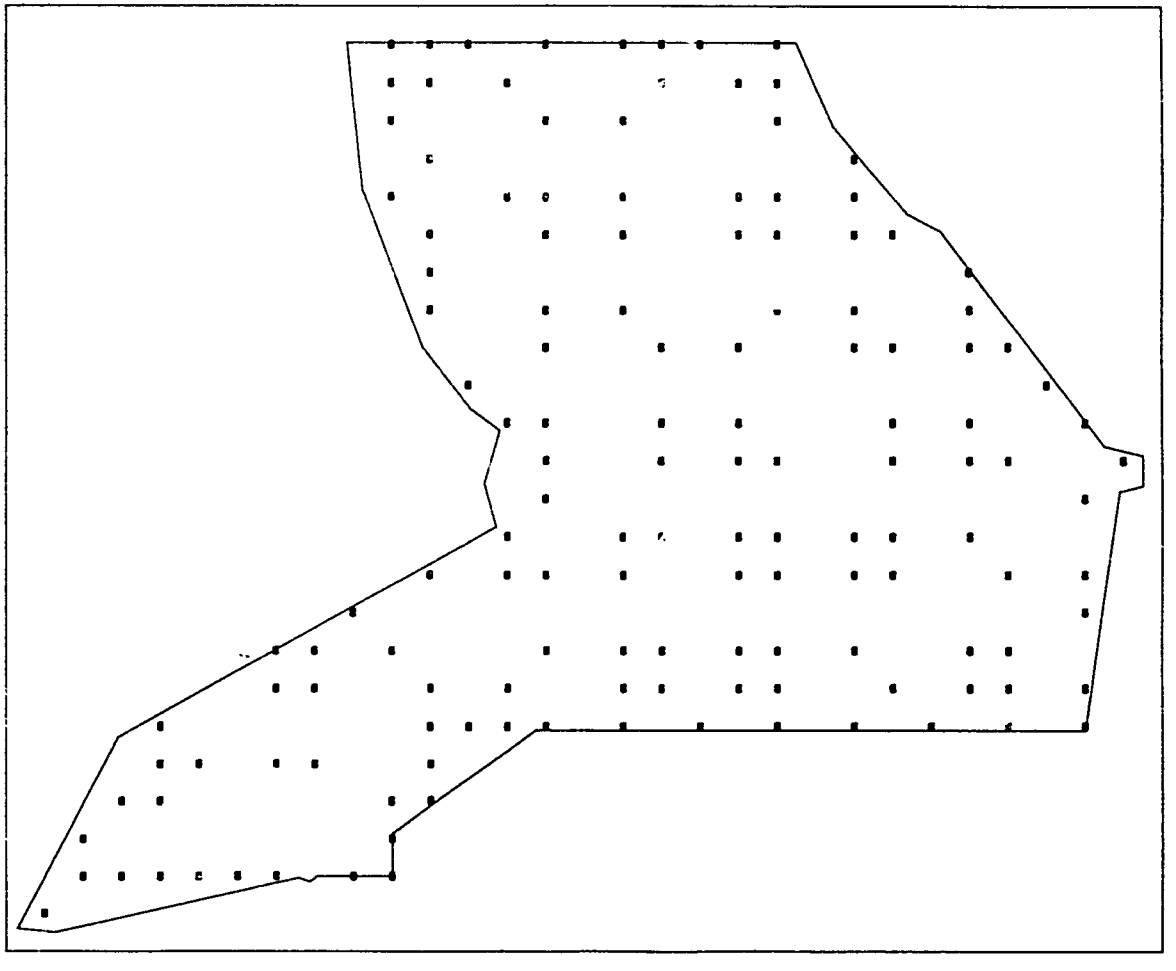

Figure 5. Location of sampling sites for calculations based on 56% of data collected.

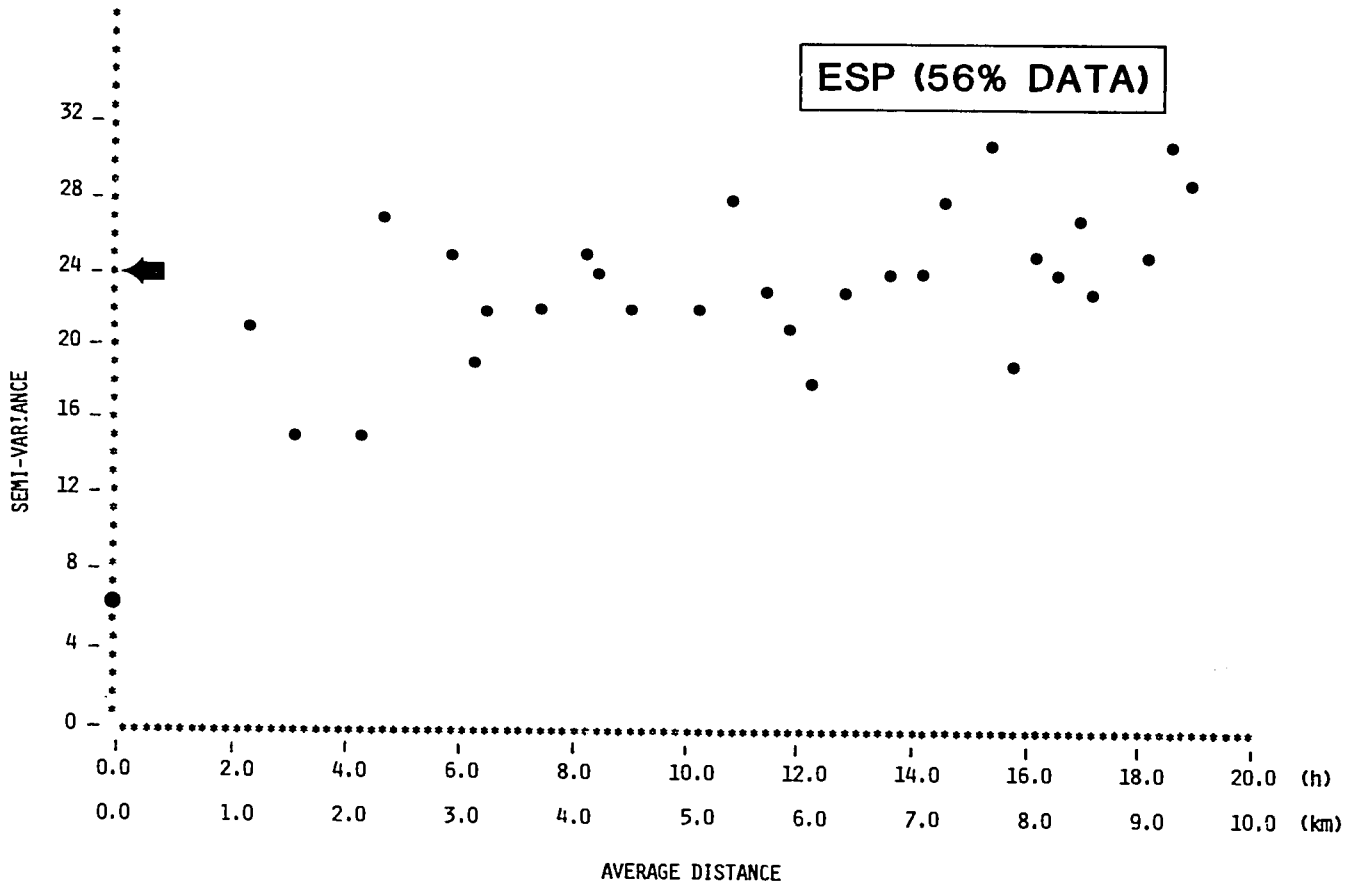

Figure 6. Semi-variogram for ESP determined from 56% (143) of samples.

A fourth semi-variogram based on 47% (119) of the sample values was poorly defined, thus preventing accurate curvefitting. Each semi-variance was calculated from at least 46 sample pairs suggesting that a shortage of sample pairs was not the cause of poor definition of the semi-variogram. A more likely cause is the inherent variation of ESP. This result suggests that the optimal number of points for geostatistical analysis of this data set was between 47% and 56% of the samples actually collected.

INTERPOLATION BY KRIGING

Kriging is an exact interpolation method of estimating values at unsampled locations by using the relationship of semi-variance with distance. By using the spatial relationship among samples described by the semi-variogram equation, kriging offers a more precise estimate of the variable at an unsampled location than means of sample values or regression estimates based on them.

Kriging is possible if the difference in ESP values between two locations within the survey area depends only on the distance between them and their orientation. If the difference does not depend on orientation, the data set is said to be isotropic. A sample calculation for kriging was given (Vander Zaag et al., 1981) in a paper presented at the 4th International Soil Classification Workshop in Rwanda.

Using the 254 sample values of ESP collected at Kenana (Fig. 1), 266 values were kriged on a 1 km square grid system based on the centroids of the original sampling grid. Comparison of iso-property maps of ESP for sampled values (Fig. 7) and kriged values (Fig. 8) shows little difference in spatial variation of ESP between maps. The pattern of variation appears smoother on the kriged map because kriged values are weighted averages of neighboring points. The accuracy of the kriged values are assessed in the form of an estimation variance computed for each kriged point. A map of estimation variance for kriged values is shown in Fig. 9.

Accuracy of the kriging procedure was checked by kriging values for sample sites where ESP had been measured. Comparisons of measured and kriged ESP values for selected locations are shown in Table 1. In Table 1, accuracy of kriging may be judged against two measured values from sites located a few meters apart. It must be remembered, however, that the kriged values in Table 1 were computed from neighboring sample values located one kilometer or more away. The estimation variance associated with each kriged value is also provided in Table 1. These results suggest that kriging is a reliable estimator of the measured values.

Based on 75% of the sample values, ESP was kriged for the same 266 locations originally kriged from all the measured data. In addition, values were kriged for the 62 locations where sample values had been withdrawn from the data set (Fig. 10). Comparison with the raw data plot (Fig. 7) shows that much of the deleted information can be recovered by kriging. At locationns where values had been withdrawn, estimation variance increased slightly (Fig. 11), indicating a decrease in the accuracy of the interpolation. This is to be expected as the interpolation is based on fewer neighboring data points.

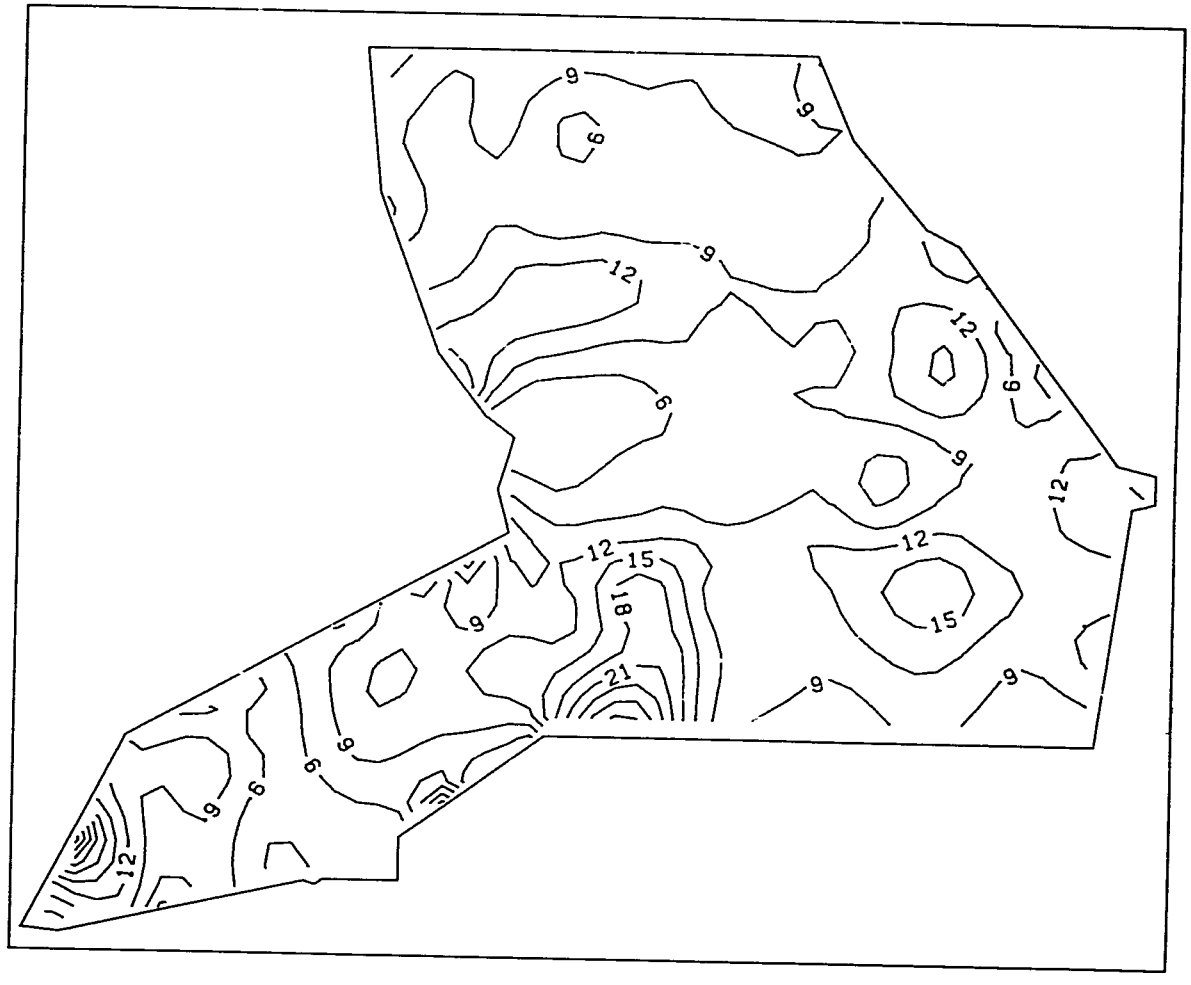

Figure 7. Map of ESP determined from 254 sampled values, Kenana Sugar Project.

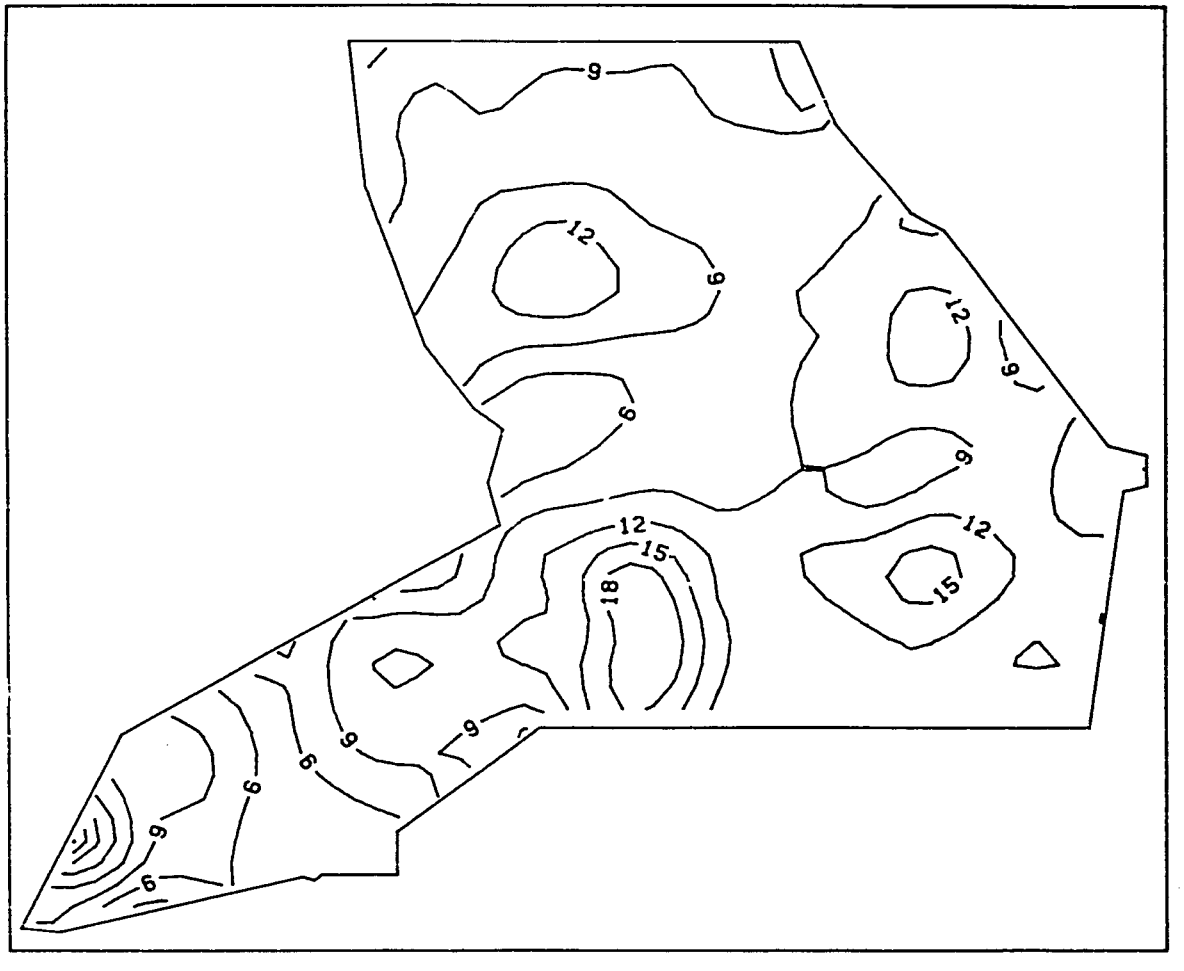

Figure 8. Map of kriged ESP values determined from 100% (254) of samples.

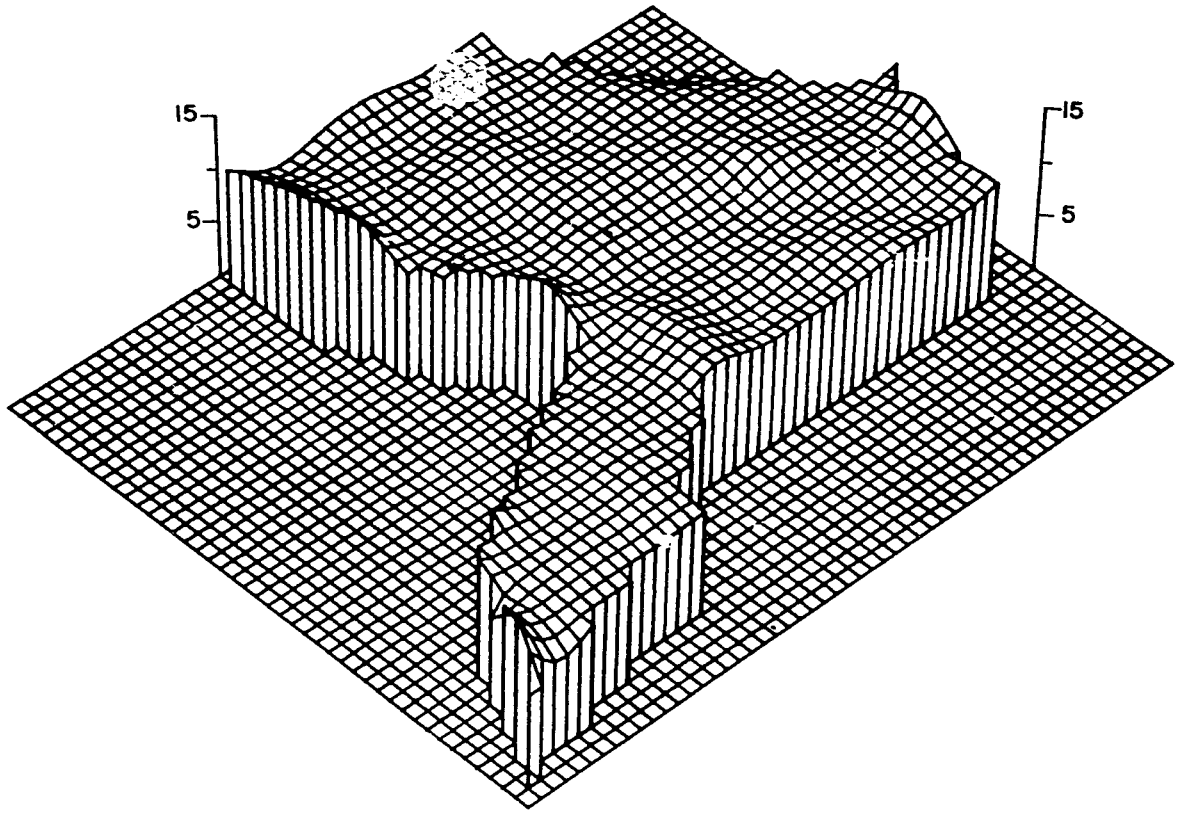

Figure 9. Plot of estimation variance for kriged ESP values determined from 100% (254) of samples.

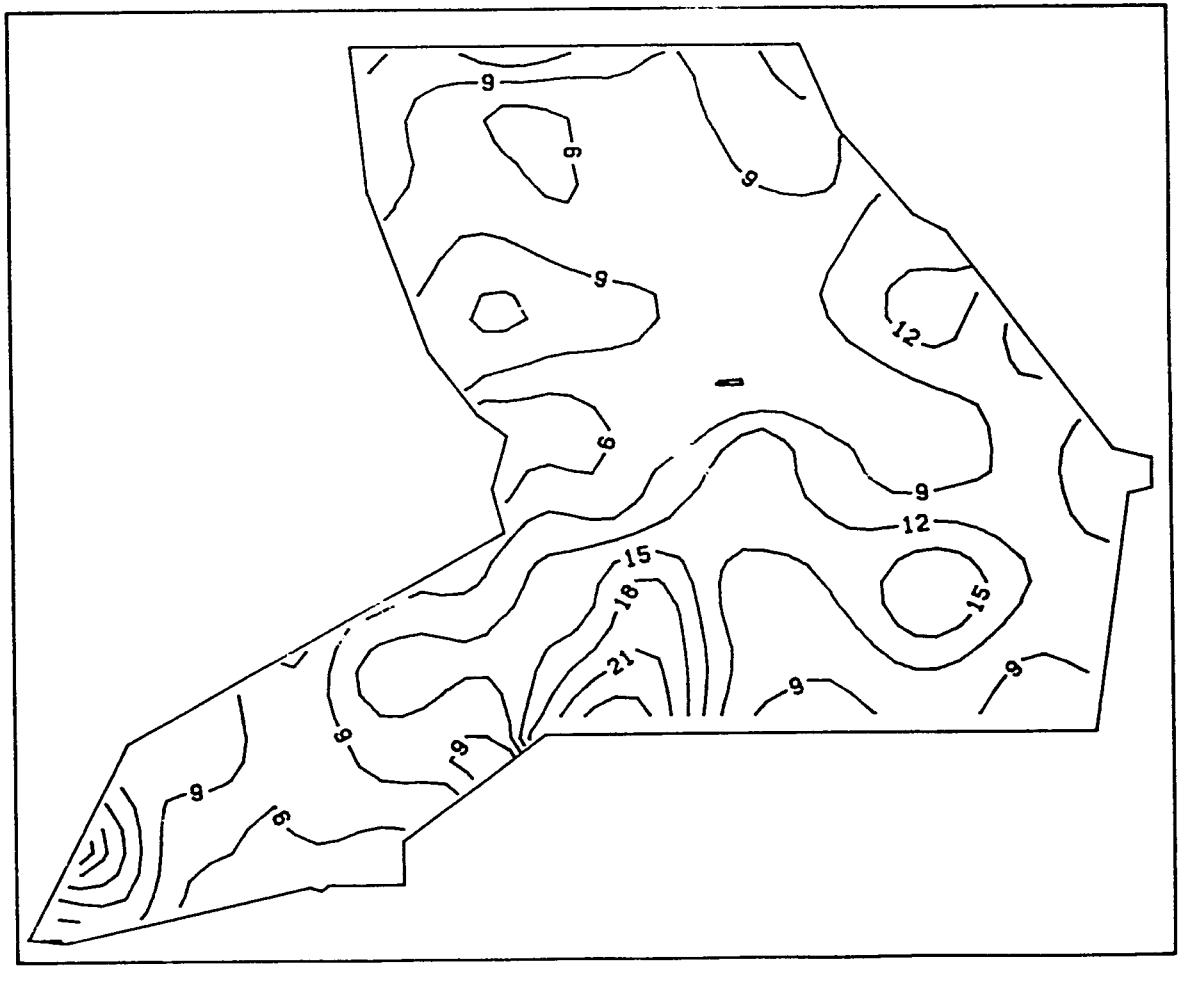

Figure 10. Map of kriged ESP values determined from 75% (192) of samples.

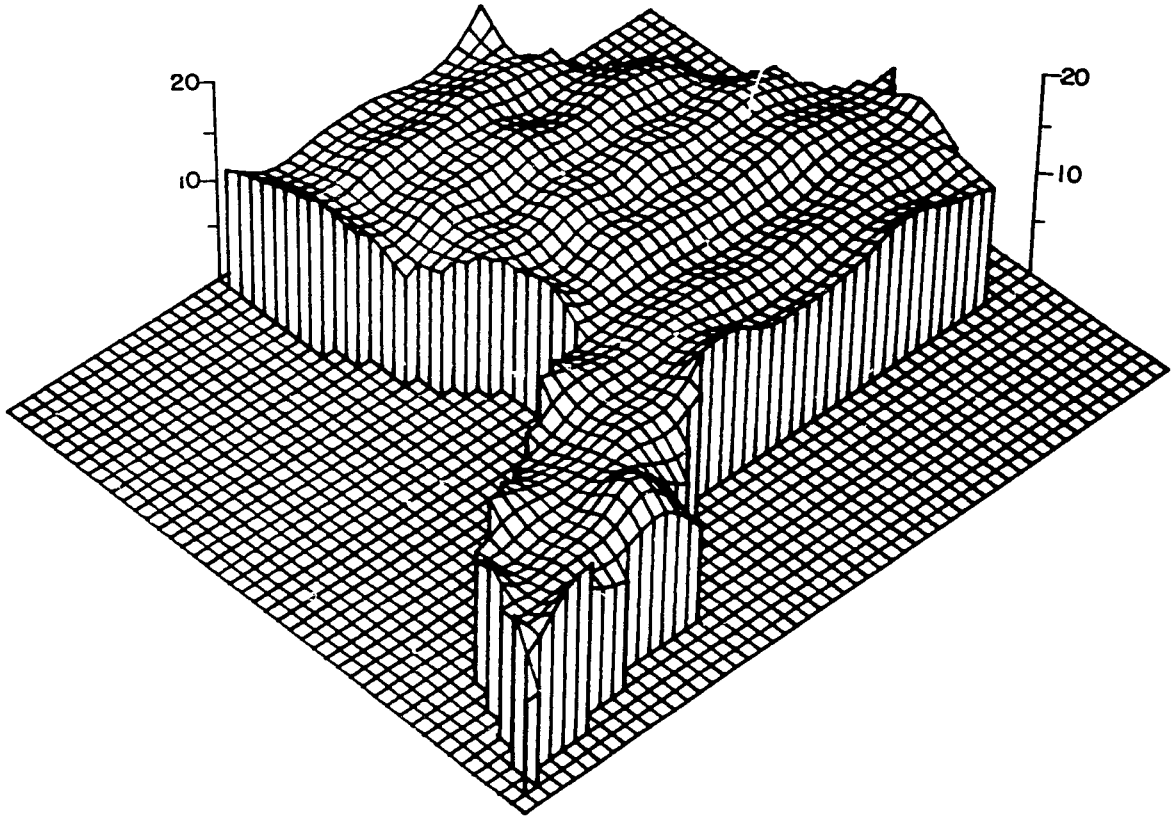

Figure 11. Plot of estimation variance for kriged ESP values determined from 75% of samples

Based on 56% of the sample values, ESP was again kriged for the same 266 locations as above, plus the 111 deleted sample locations (Fig. 12). Although some detail is lost, the kriged map, based on 56% of the original data, still clearly shows the main trends of ESP in the Kenana sugar project site. A decrease in accuracy of the interpolation based on 56% of the points is shown by a slight increase in the mean estimation variance (Table 2) and in complexity of the estimation variance map (Fig. 13).

If geostatistics had been available to the researchers of the Kenana sugar project, sampling for ESP could have been reduced to about 56% of the data actually collected with only slight loss in estimation precision (Table 2). Any additional samples could have been collected more profitably at distances less than 1 km apart. This would have improved the curvefitting of the semi-variograms and given a more accurate description of short range variability. It would also have enabled estimation of the zero intercept of the semi-variogram without the need for double sampling as in Table 1.

These results clearly show the usefulness of geostatistics as an aid to conventional soil survey. By producing similar results from a reduced number of samples, geostatistics can be used to increase the efficiency of time and effort expended in soil survey. The accuracy and precision of interpolating values at unsampled locations can also be increased by using geostatistics.

Table 2. Effect of reducing sample size on the semi-variogram and mean estimation variance of kriged values.

Percent of samples used in analysis (n = 254)	Semi-variogram		Mean estimation variance
	Intercept	Sill	
100	6.15	21.6	10.5
75	6.15	22.1	12.2
56	6.15	24.0	13.1
47	-	-	

CONCLUSIONS

Isotropic semi-variograms indicate that samples of exchangeable sodium percentage (ESP) in the 0-25 cm soil depth are spatially related over distances of 3.5 - 4.0 km in the Kenana sugar project, Sudan. Semi-variograms calculated from 100% (254), 75% (192) and 56% (143) of the measured samples

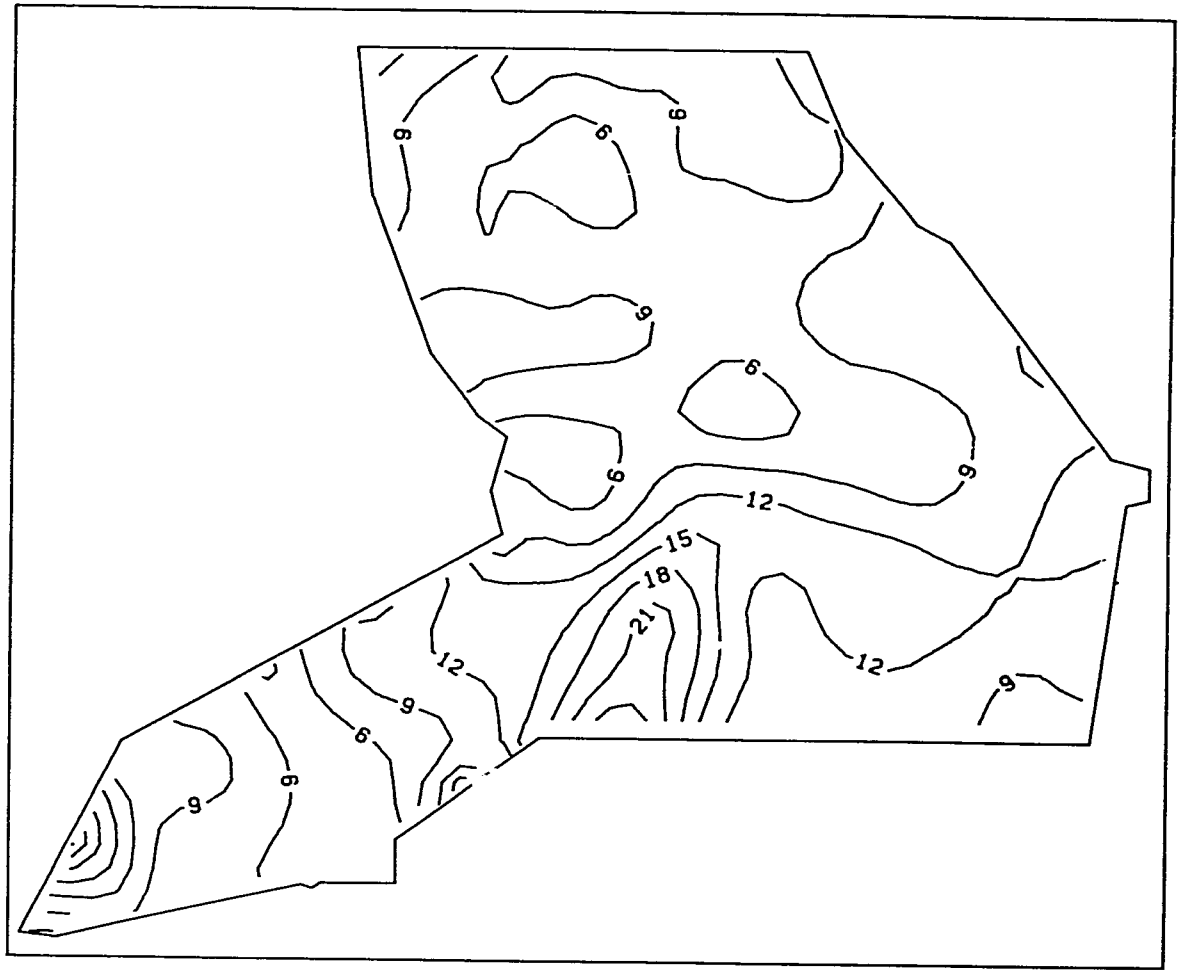

Figure 12. Map of kriged ESP values determined from 56% (143) of samples.

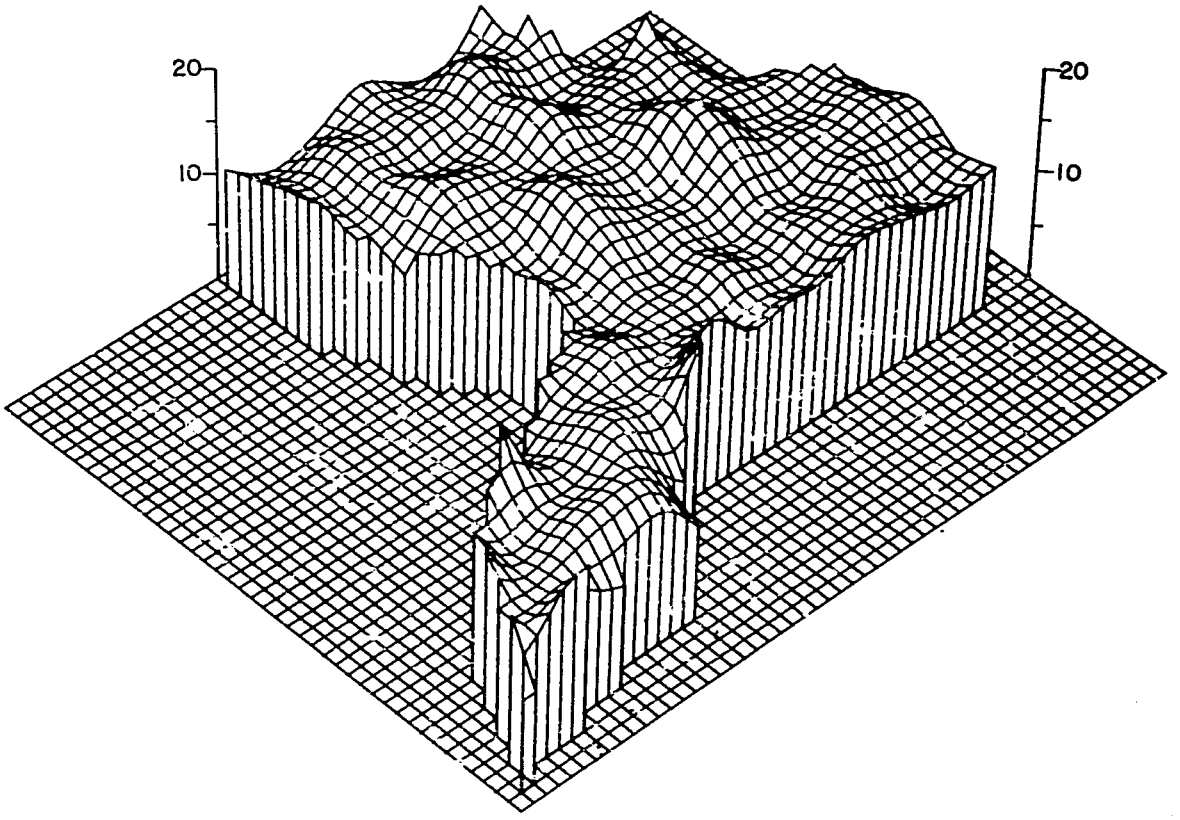

Figure 13. Plot of estimation variance fro kriged ESP values deterimined from 56% of samples.

showed similar structure in the relationship between semi-variance and distance. This structure was lost when 47% (119) of the sample values were used.

Kriged maps of ESP calculated from 100%, 75% and 56% of the total samples showed similar patterns of variation in ESP to the map based on the original sample values. This suggests that if geostatistics had been available during the soil survey, sampling for ESP could have been reduced to about 56% of the data actually collected.

Geostatistics can aid soil survey and land evaluation by exploiting structure in the variance of spatially related soil properties. This information can be used to estimate values at unsampled locations from a minimum number of sample points, thus increasing the efficiency of data collection, analysis, and interpretation.

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APPLICATION OF PEDOLOGY TO PLANT RESPONSE PREDICTION FOR TROPICAL VERTISOLS

R B. Grossman, W. D. Nettleton, and B. R. Brasher

Water deficiency and tilth are undoubtedly the most important plant growth considerations for the management of Vertisols. Lack of water is a problem at times in all Vertisols because taxonomic criteria dictate that they must have desiccation cracks at 50 cm depth in most years (Soil Survey Staff, 1975). Presence of cracks implies that there are at least seasonal periods of high water suction or water deficiency. Because the cracks must exceed 1 cm in width, extensibility must be propagated horizontally over appreciable distances. If roots grow mostly in the widely spaced desiccation cracks and there is a degree of restriction to entry from the cracks into the bounding soil fabric, then there is the possibility of incomplete water removal. This potential water deficiency problem of Vertisols is investigated by an analysis of laboratory water retention and bulk density measurements. The possibility of a mechanical root restriction is also explored.

Unfavorable tilth of Vertisols shows up in problems of seedbed preparation, seedling emergence, and a high energy requirement for tillage. In parts of the United States, Vertisols and related soils are referred to as "ten-to-noon" soils because of the short period they are in a suitable water state to till. In this paper, we consider only a few aspects of this large subject. In particular, we explore certain differences between Pellusterts and Chromusterts and summarize the physical properties of Vertisols that are related to granular surface mulches and blocky and prismatic Bw horizons.

In passing, it is of historical interest that differences in physical properties of surface horizons were at a high categorical level in an early Soil Taxonomy approximation. Soils with granular surface horizons were separated from those that crust (Soil Survey Staff, 1960).

The problems we address require observations on soils throughout the year in order to document soil conditions relative to farming decisions. The pedons to be discussed were observed for only a short period in the field. Information on the yearly pattern of water states, or the seasonal pattern of soil moisture suctions, and the physical condition of the tillage zone is sketchy. In particular, we lack in respect to water availability, measurements in the field such as those shown for Vertisols of India (Russell, 1980, Fig. 1).

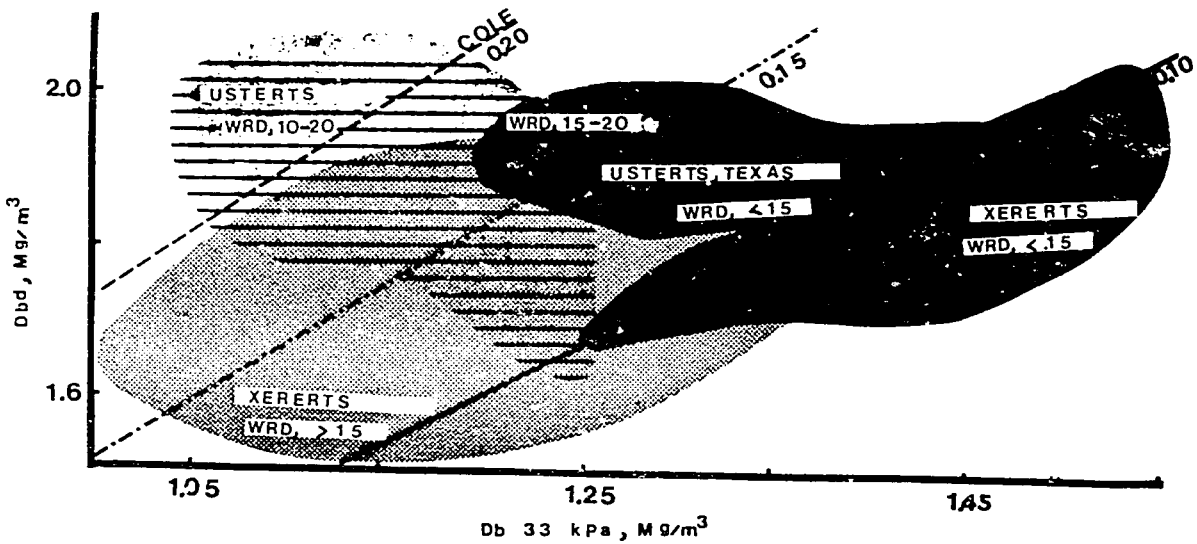

Figure 1. Water retention difference classes in a field of dry vs. moist bulk density.

Regional difference in moist bulk densities

A plot of dry bulk density versus moist bulk density (Fig. 1) separates Vertisols of ustic, udic, and xeric moisture regimes and tends to cluster them into three groups. Some Usterts from the United States, and possibly the Uderts also, tend to have higher dry bulk densities and lower moist ones than do Xererts. The difference is apparently independent of clay percentage. The Uderts and Usterts probably go through more wet and dry cycles than do the Xererts, which may be a contributing reason for the difference in bulk density. The large differences in moist bulk density have a possible important implication for water relationships among the suborders. As will be developed, soils with high moist bulk density and linear extensibility should reach a root-restricting bulk density after relatively less of the laboratory measured available water has been removed.

Bulk density at intermediate water content

Vertisols have high extensibility, or ability, to change in dimension on going from a dry to a moist state. As drying progresses, the fabric cracks and the soil bounded by the cracks increases in bulk density relative to the bulk density of the whole soil. At the National Soil Survey Laboratory, we measure bulk density at tensions of 33 kPa and over-dryness as end points. Bulk density at intermediate water content may be calculated (Grossman et al., 1981). The bulk density of immediate interest excludes desiccation crack space. It is not the bulk density of the soil as a whole, but rather of the fabric bounded by desiccation cracks having repeat distances greater than the approximately 8 cm diameter of the bulk density clods. The calculation of the bulk density of the fabric at intermediate water content (Dbi) rests on the assumption of equal contraction along the three principle axes (Fox, 1964, Fig. 1). Shrinkage occurs from 33 kPa (the field capacity estimate) to oven-dryness through two regions (Fig. 2). Between 33 kPa and a variable lower limit, we assume a linear increase in bulk density as water content decreases. Below this variable lower limit, we assume no increase in bulk density on further drying. The arithematic expression for the bulk density at intermediate water content follows:

$$Dbi = Db + \frac{(Dbd - Db) \times (W33 - Wi)}{W33 - (F \times W1500)}$$

Db is the bulk density of the clod at 33 kPa water retention, Dbd is the bulk density of the oven-dry clod, W33 and W1500 are the weight percentages at 33 and 1500 kPa respectively, Wi is the intermediate water content (the subject of the next section), and F is the factor by which W1500 is reduced. The factor, F, is lowered as the coefficient of linear extensibility (COLE) increases:

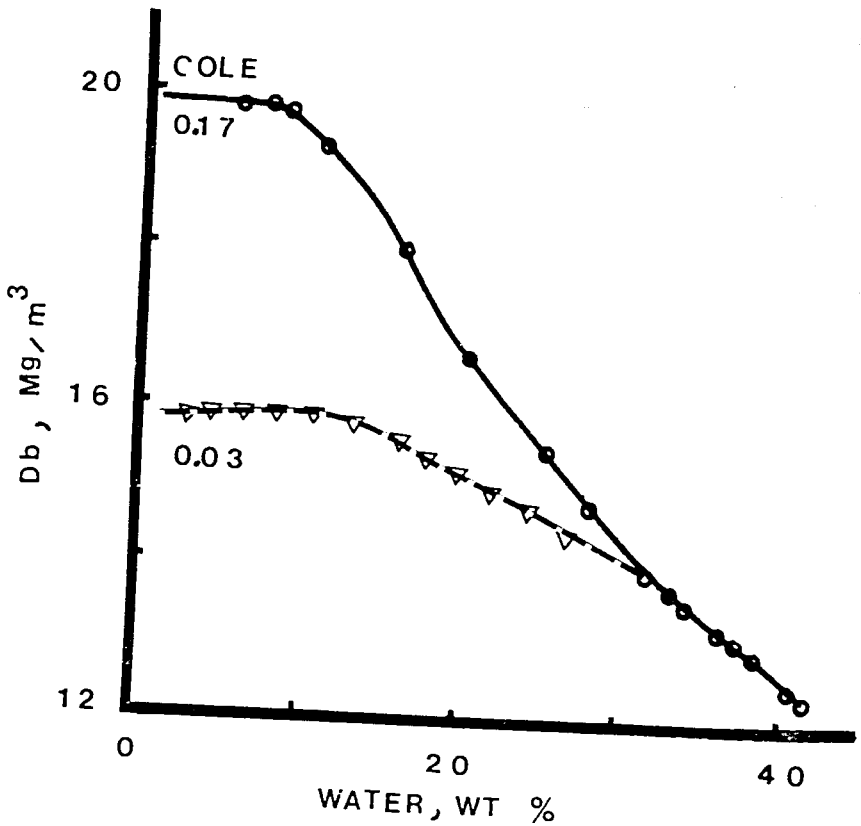

Figure 2. Plot of change in bulk density upon loss of water for two soil clods having large differences in COLE

COLE (4D1)[a]	F
< .06[b]	.6
.06 - .09	.5
.09 - .12	.4
> .12	.3

[a]Code refers to the method of measurement in Soil Conservation Service (1972). COLE is the strain per unit length of dry soil fabric on drying from a suction approximating field capacity to oven-dryness. It is calculated from the change in volume of clods coated with a flexible plastic. Linear extensibility = COLE x 100.

[b]Applicable for soil materials with over 18% clay.

The calculation is a generalization based on measured shrinkage curves by Brasher (1963), McKeen and Nielsen (1978), Lautritzen (1948), and Reeve and Hall (1978). It is intended for use with fine-textured soils only because the amount as well as the kind of clay influences the shape of the shrinkage curve. Two plots of measured bulk densities (equivalent to Dbi) against the weight percent water for soil horizons with markedly different COLE values show the progressive changes (Fig. 2). Both reach water contents below which shrinkage is near zero. The curve for the soil horizon with the lower COLE reaches near zero shrinkage at a higher water content relative to 1500 kPa retention than does the one having the higher COLE. The horizon with the lower COLE would have an F of 0.6 and the one with the higher COLE an F of 0.3 in our proposed relationship.

Desiccation cracks

Below 30 cm depth, mechanical constraints on the fabric are appreciable, structural units are rather large and at field capacity mechanical constraint of the fabric on the root is moderate or weak. Vertisols, when very moist or wet, do not commonly restrict root entry into horizons. As drying progresses, vertical cracks appear adjacent to the larger roots. Lateral root restriction by the vertical cracks increases as drying progresses because soil fabric becomes denser, stronger, and hence, more resistant to root entry. Evaporative loss from cracks (Adams et al., 1969; Ritchie and Adams, 1974) and removal of water by roots concentrated in the cracks increases the strength of the soil adjacent to the cracks relative to that of the bulk soil and leads to greater root constraint than might be indicated by the water content of the overall horizon. Root entry then is largely restricted to the moist soil below the bottom of the cracks and the cracks follow the roots as they penetrate deeper into the soil.

The cracks in Vertisols can be viewed as three groups (Fig. 3). The vertically oriented cracks that outline the prisms of the first group are relatively wide, usually exceeding 5 mm at appreciable deficits from field capacity, and develop progressively deeper as further drying occurs. The

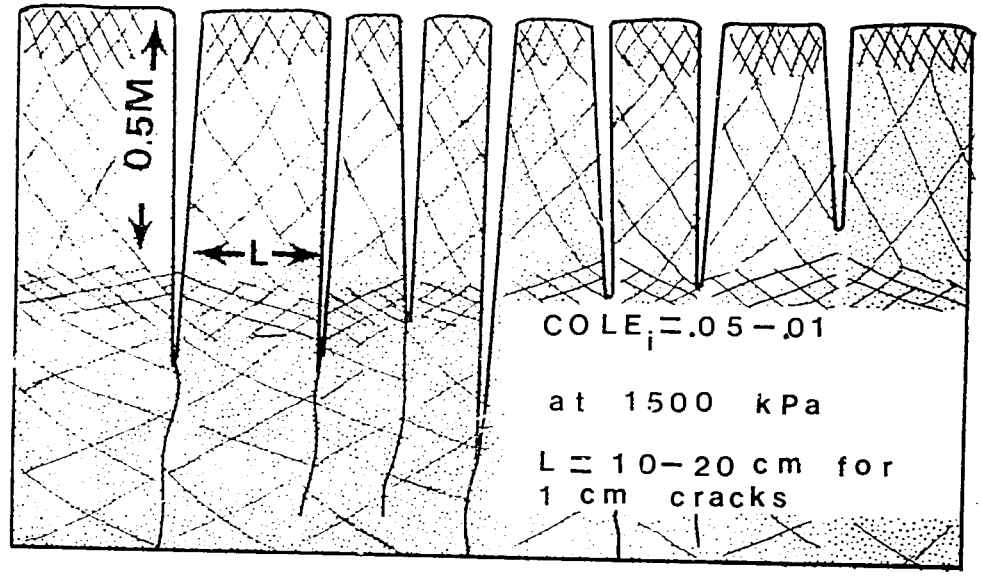

Figure 3. Drawing of cross section of a Vertisol showing two kinds of cracks that develop upon drying.

randomly oriented narrow cracks, a mm or less in width of the second group, tend to be closer together, and do not develop until water contents are around 1500 kPa retention. These outline the angular blocks. These latter cracks have less importance as regards root ramification because at the water content where they form, the soil fabric has reached a strength where root entry is limited. Furthermore, suction is so high the available water content is small. A third group of cracks occur at about a half meter depth, are formed by soil movement, and are made up of intersecting slickensides. The low angles at which these intersect give this zone a platy appearance.

The wider cracks that are initiated upon drying from field capacity tend to be separated by appreciable distances. These distances are sufficient to suggest that roots constrained within the cracks cannot exploit the water farthest from the cracks. The definition of Vertisols in fact requires that the repeat distance be considerable in order to have 1 cm wide cracks.

Crack repeat distance may be calculated based on the COLE for intermediate water content reduction (COLEi). The calculating relationship assuming no rock fragments is as follows:

$$\frac{Dbi}{Db}^{1/3} - 1$$

Where Db is the bulk density at 33 kPa water retention and Dbi is the calculated bulk density for the intermediate water content previously discussed.

Table 1. Calculated bulk density and COLE at 1500 kPa retention for three horizons of Sudanese pedons.

Sample No.	Bulk Density (4A1)[a]			Water Retention (4Bs)		COLE (4D1)	COLEi
	33 kPa	1500 kPa	Oven-dry	33 kPa	1500 kPa		
	---------- Mg/m^3		----------	---- Volume % ---			
1318	1.05	1.46	1.99	49.2	32.2	.238	.110
1339	1.20	1.55	2.06	41.7	28.3	.197	.089
1362	1.12	1.31	1.56	36.5	24.9	.117	.054

[a]Codes refer to methods in Soil Conservation Service (1972).

Table 1 gives COLEi at 1500 kPa retention for three samples that cover much of the range in COLE to be expected for Vertisols. Values of COLEi at 1500 kPa retention range from roughly .050 to 0.10. In order to have a crack 1 cm wide at a water content corresponding to the 1500 kPa retention, the estimated repeat distance between the cracks would range from 10 to 20 cm (Table 2). Even if the extensibility to oven-dryness were utilized (regular COLE), the repeat distance for 1 cm wide cracks would only drop to between 5 and 10 cm. Even this repeat distance is sufficient to raise

the question of incomplete water withdrawal by roots if restricted to cracks. In short, the definition of Vertisols requires propagation of shrinkage over distances of several centimeters raising the distinct possibility of incomplete water utilization if roots are strongly restricted to cracks.

Table 2. Distance between cracks of various widths for two values of COLEi at 1500 kPa retention.

Crack width	Distance between cracks COLEi = 0.05	COLEi = 0.10
mm	cm	cm
1	2	1
2	4	2
5	10	5
10	20	10
50	100	50
100	200	100

Root-limiting bulk density

Table 3 summarizes several studies on bulk density and root restriction which are applicable to fine-textured soil materials. The range of 1.40 to 1.50 Mg/m^3 would seem to be where mechanical restriction becomes strong. The studies were made on disaggregated soil material that presumably was homogeneous and did not contain planes of weakness into which the roots could enter. The studies are relevant to the bulk density exclusive of desiccation crack space, Dbi, the computation of which has been discussed.

The study by Greacen et al. (1968, Fig. 5), is of particular interest. They report that as the angle of contact between root and soil departs from 90° , the bulk density at which root entry is limiting decreases. The study suggests that roots in vertical cracks may be restricted from entry into the soil fabric by lower bulk densities than would be predicted by measurements involving vertical root growth. In view of the study by Greacen et al. (1968), and the likelihood that entry of roots from vertical cracks into adjacent fabric is the principle question, we assume that the low end of the range of 1.40 to 1.50 Mg/m^3 would apply to Vertisols. A root-limiting bulk density of 1.40 Mg/m^3 is therefore assumed.

Table 3. Literature on root restriction due to bulk density of fabrics made from disaggregated soil.

Reference	Crop	Criterion	D_b Mg/m^3	Notes
Champion & Barley (1969)	Peas	Zero penetration of radicle	1.26	65% clay; kaolinite and illite; remolded; root hairs; saturated at all bulk densities; oxygen defusion
Gerard et al. (1972)	Cotton	40-50% reduction in root elongation from a bulk density of 1.40 Mg/m^3	1.50	Clayey texture, percentage not given; reduction pertains to perpendicular radicle elongation.
Cockcroft et al. (1969)	Peas	Zero penetration of radicle	1.46	65% clay; not remolded; 5 kPa water state.
Greacen et al. (1968)	Peas	See notes	--	Loam texture. Radicle entry into soil slabs as a function of departure from 90°. Bulk density at which radicle entry is markedly reduced, decreases as the angle of slab to the horizontal increases.
Hemsath & Mazurak (1974)	Sorghum	About 60% reduction in root	1.50	30% kaolinite clay; remainder fine sand; 3-day root penetration of planted seedlings.
Meredith & Patrick (1961)	Sudangrass	25% reduction root penetration from a bulk density of 1.20 Mg/m^3	1.50	35% clay; sieved through 5 mm sieve; maintained at 50% available water; air-filled pore space above 10%.
Trouse (1977)	Wheat	About 80% reduction in elongation rate from a bulk density of 1.10 Mg/m^3	1.44	Controlled environment simulates range of growing season conditions.
Voorhees et al. (1975)	Peas	About 50% reduction root penetration from a bulk density of 0.99 Mg/m^3	1.37	55% clay; germinating peas grown into cores formed of soil passing 2 mm sieve; held at 33 kPa water state.

Table 4. Means of clay, water retention, linear extensibility (L.E.), exchangeable sodium percentage (ESP), bulk density (D_b33, Dbd) and water retention difference (WRD) for A and Bw horizons of Vertisols.

Horizon	Clay	Water Retention @ 33 kPa	Water Retention @ 1500 kPa	L.E.	ESP	Db33 (Mg/m³)	Dbd (Mg/m³)	WRD (cm/cm)
	(%)							
Torrerts from New Mexico (3) and Sudan (1):								
A	51 ± 11	29 ± 7	18 ± 3	7.5 ± 4	7 ± 14	1.32 ± .07	1.63 ± .10	.15 ± .06
Bw	53 ± 11	31 ± 5	20 ± 4	8.4 ± 2	10 ± 16	1.29 ± .13	1.63 ± .10	.14 ± .02
Usterts from Texas (3) and Arizona (1):								
A	48 ± 3	29 ± 4	18 ± 1	10.4 ± 1	1 ± 1	1.37 ± .07	1.84 ± .09	.14 ± .03
Bw	49 ± 3	31 ± 3	20 ± 1	10.8 ± 1	3 ± 5	1.34 ± .08	1.82 ± .13	.14 ± .03
Usterts from Sudan (4):								
A	64 ± 9	38 ± 6	25 ± 4	15.2 ± 5	6 ± 6	1.18 ± .08	1.81 ± .16	.16 ± .02
Bw	65 ± 9	40 ± 6	25 ± 4	16.8 ± 4	13 ± 8	1.18 ± .08	1.88 ± .13	.17 ± .02
Chromusterts from Hawaii (4):								
A	--	31 ± 3	25 ± 4	7.8 ± 4	6 ± 6	1.33 ± .08	1.67 ± .22	.09 ± .01
Bw	--	34 ± 4	27 ± 5	7.1 ± 4	11 ± 12	1.29 ± .11	1.57 ± .25	.09 ± .03
Xererts from California (3) and Idaho (1):								
A	55 ± 7	38 ± 7	25 ± 5	11.5 ± 2	1 ± 1	1.22 ± .15	1.68 ± .15	.14 ± .06
Bw	55 ± 6	37 ± 7	26 ± 5	11.0 ± 1	6 ± 9	1.26 ± .15	1.73 ± .17	.14 ± .08
Uderts from Texas (4):								
A	56 ± 6	35 ± 6	24 ± 4	13.2 ± 4	3 ± 3	1.27 ± .10	1.86 ± .05	.15 ± .02
Bw	59 ± 4	35 ± 5	24 ± 3	14.1 ± 3	4 ± 3	1.31 ± .09	1.95 ± .02	.14 ± .03

Laboratory water retention difference

The standard laboratory water retention difference is the difference in water content between that held at 33 kPa and that held at 1500 kPa. It is an estimate of the available water at field capacity.

Comparable horizons of Vertisols differ by threefold in laboratory water retention difference. When summarized by horizons for taxa from different areas, means of water retention difference differ by about twofold (Table 4). Usterts from Sudan appear high, Usterts from Hawaii low and Torrerts from New Mexico and Sudan have intermediate water retention differences. Clay percentage, water retention at 1500 kPa and extractable cations do not seem responsible. There is a tendency for water retention difference to be lower as the moist bulk density increases. For example for the individual horizons on which the summaries of Table 4 are based, there are no water retention difference values of .20 or more above a moist bulk density of 1.24 Mg/m^3 and none with .15 or more above 1.37 Mg/m^3.

Table 5 may be helpful in understanding the relationship between water retention difference and bulk density. The bulk densities were computed by back calculation from the total porosity which in turn was set equal to the sum of the volumetric water retention at 1500 kPa, the laboratory water retention and an assumed air-filled porosity at 33 kPa retention of 8%. The air-filled porosity selected is very close to the median of 9% for 16 subsoil horizons of Sudanese Vertisols. As an example, the table shows that for the air-filled porosity assumed, horizons with water retention differences of 0.20 or more and over 50% clay must have bulk densities below 1.25 Mg/m^3, which is in agreement with the data examined.

Table 5. Computed bulk density for three water retention differences and several clay percentages.

Clay	Bulk density for three water retention differences[a]		
	0.10%	0.15%	0.20%
(%)	----------	Mg/m^3	----------
40	1.53	1.43	1.34
50	1.42	1.34	1.25
60	1.33	1.25	1.17
70	1.25	1.17	1.10
80	1.18	1.11	1.03

[a]Assumes 8% air-filled porosity at 33 kPa water retention and a ratio of 1500 kPa retention to clay of 0.4.

Adjustment of laboratory water retention difference for root restriction

In previous sections we discussed calculation of the bulk density exclusive of desiccation crack space, Dbi, and the value of Dbi that might place strong mechanical restriction on the horizontal entry of roots from vertical cracks into the bounding soil fabric. In this section we consider the calculation of the water content at which mechanical root restriction may be expected. The calculating relationship for the water content, Wi, at a bulk density of 1.40 Mg/m^3 is as follows:

$$Wi = W33 - \frac{(1.40 - Db) \times (W33 - F \times W1500)}{Dbd - Db}$$

Where the quantities are the same as in previous equations and 1.40 has been substituted for Dbi.

An immediate question raised by the previous section is whether the water content for a calculated bulk density of 1.40 Mg/m^3 exceeds the 1500 kPa retention. In other words, may mechanical restraint of roots in cracks occur at higher water content than the generally accepted lower limit of water availability?

The answer depends on characteristics of the soil material and cannot be generalized simply. Fig. 4 shows the calculated water content, Dbi, and the bulk density of 1.40 Mg/m^3 for three samples with different properties. The data for these samples are in Table 1. For sample 1339, Wi at a bulk density of 1.40 Mg/m^3 is approximately halfway between the retention of 33 and 1500 kPa. This suggests that an appreciable part of the standard water retention difference is present when the horizon reaches a bulk density that restricts horizontal root entry from the desiccation cracks into adjacent fabric. The effective water retention difference would, therefore, be reduced from that calculated from standard laboratory data. In contrast for samples 1318 and 1362, Wi at a bulk density of 1.40 Mg/m^3 is at or below the 1500 kPa retention; therefore, for these samples, mechanical root restriction would appear not to reduce the amount of available water from that measured in the laboratory. Sample 1339 in Fig. 4 requires a relatively small increase in bulk density upon drying to reach a bulk density of 1.40 Mg/m^3. Compared to sample 1362, the curve has a high slope angle as a consequence of having high COLE and the intercept along the horizontal line depicting a bulk density of 1.40 Mg/m^3 is relatively far to the right and above the 1500 kPa retention.

Examination of standard characterization data supports the analysis shown in Fig. 4. Fig. 5 relates to the proportion of the laboratory water retention difference that is exhausted at a bulk density of 1.40 Mg/m^3 to the respective moist and dry bulk densities. The proportion of the laboratory water retention difference exhausted at a bulk density of 1.40 tends to be smaller as the moist bulk density rises and also as the linear extensibility rises.

Finally, laboratory water retention difference tends to decrease with increasing moist bulk density. Therefore, as moist bulk density rises, we possibly have two additive effects: the greater likelihood of mechanical

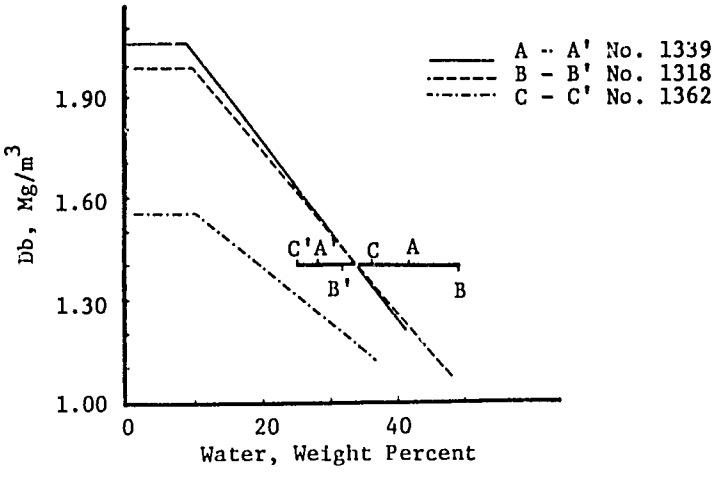

Figure 4. Generalized drying curves for three horizons of Vertisols with the 33 to 1500 kPa water retention points (A-A', B-B', C-C') at a Db of 1.3 Mg/m^3. Sample no. 1339 is the Bw2 horizon of Roseires (835-11), no. 1318 is the Bw2 horizon of Dinder (835-10), and no. 1362 is the Bwk2 horizon of Eilafun (835-17).

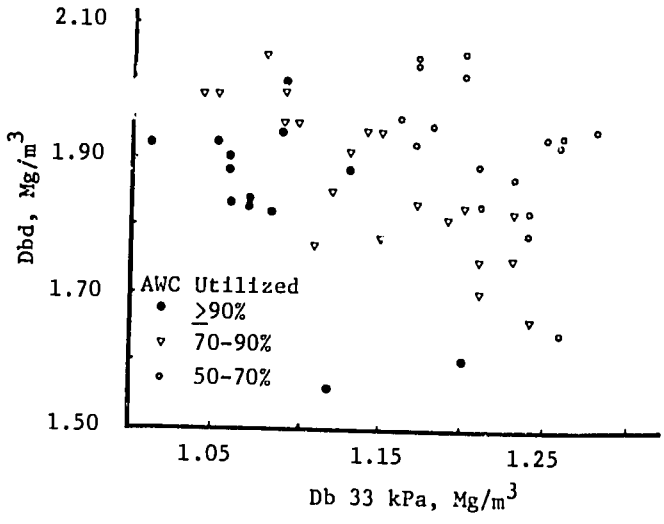

Figure 5. The percent of the laboratory available water capacity (WRD) removed when the soil reaches a bulk density of 1.40 Mg/m^3.

root restriction with resultant incomplete exploitation of the standard water retention difference and a tendency for the standard water retention difference to be smaller.

The argument can be made for more attention to moist bulk density as a criterion for soil separation within Vertisols, particularly if combined with linear extensibility. Some possible generalizations for the estimated reduction in the effective water retention difference are given in Table 6.

Table 6. Estimated reduction in measured water retention difference for different combinations of moist bulk density (D_b) and COLE.

Moist bulk density at 33 kPa (Mg/m^3)	Reduction in effective WRD COLE <.15	COLE >.15
	(%)	
< 1.25	< 25	25-50
≥ 1.25	25-50	> 50

TILTH OF VERTISOLS

The other agronomic problem posed by Vertisols is unfavorable tilth. Cultivation of Vertisols by primitive agricultural methods was difficult enough that it was considered as an explanation for the general absence of prehistoric villages in the so-called "cultural sink" which occurs in the Vertisol area of East Texas (Duffield, 1970).

The Grumaquert-Mazaquert separation of the 7th Approximation (Soil Survey Staff, 1960) used the tilth of Vertisols as a criterion, but the approach was abandoned when it was learned that use and management could greatly alter the structure of these soils from that found in uncultivated areas.

Of the taxa we examined, the Xererts and Uderts tend to have the thinnest granular surface mulches and some of these soils lose the mulch entirely on cultivation. The Usterts tend to have the thickest mulches and the Chromusterts thicker ones than the Pellusterts.

We studied dithionite-citrate extractable Fe content and the Middleton (1930) dispersion ratios for the Vertisols of Sudan (Table 7). The Typic and Entic Chromusterts have a thicker surface mulch, a higher extractable Fe content, a lower dispersion ratio, and disperse at a lower Na concentration than the Pellusterts indicating that Chromusterts have a higher aggregate stability than do Pellusterts. The differences are small, however, and there is some overlap. The ease of breakdown of 2 to 1 mm aggregates was also compared for the second horizon of pedons of Pellusterts and

Chromusterts. Disaggregation was measured by the percent retained on a 0.5 mm screen after wet-sieving. The Chromustert samples were more resistant to breakdown on application of a variation of the sodium-saturation test of Emerson. In this test, samples premoistened against 5 kPa suction were equilibrated against 1.00N NaCl to sodium saturation and then equilibrated at progressively lower concentrations of NaCl until retention on the sieve dropped below 50%. Retention dropped below 50% at a concentration of 0.15N NaCl for the Pellustert samples and of 0.10 to 0.15N for the Chromustert samples.

Table 7. Clay, Middleton dispersion ratio, mulch thickness and extractable Fe contents of A horizons of three Chromusterts and three Pellusterts from Sudan.

Horizon	Depth (cm)	Clay < 2μm (3A1) (%)	Dispersion[a] Ratio	Mulch[b] thickness (cm)	Dithionite-citrate ext. Fe (6C2B) < 2 mm soil (%)	Clay < 2 μm (%)
	Typic and Entic Chromusterts (NSSL Nos. 1334, 1276, and 1408)					
A2	12-30	50.0	0.11	N.A.	2.8	N.A.
Ap2	10-25	58.6	0.16	10	2.2	2.5
A2	2-12	66.0	0.19	4	3.8	4.9
	Typic and Entic Pellusterts (NSSL Nos. 1310, 1401, and 1395)					
A2	5-25	57.6	0.18	0	1.5	N.A.
A2	3-10	71.4	0.28	3	1.6	1.9
A2	2- 8	42.6	0.25	2	0.7	1.2

[a]Ratio of clay plus fine silt (< 20 μm) dispersed by brief agitation in water alone to that dispersed by standard dispersion (Middleton, 1930).
[b]Surface mulch = fine granular or subangular blocky material.

Codes refer to methods in Soil Conservation Service (1972).

The differences in thickness of surface mulch between the Chromusterts and Pellusterts then are possibly a result of formation environment. The Pellusterts usually occur in former river channels and become saturated or even ponded for short periods during the monsoon season. During the monsoon season, Fe is reduced and gradually removed from the profiles. Removal of the Fe makes the clays more susceptible to dispersion (Hallsworth, 1963). Upon drying, these clays tend to aggregate into larger units producing a less favorable tilth.

Chromusterts in contrast do not become as wet as the Pellusterts. Evidence for this is their higher chroma. Further, they may wet at a higher

tension and in addition wet and dry more frequently than do the associated Pellusterts. Such wetting and drying where zero suction is not reached reduce aggregate size and produce a surface mulch.

The granular surface mulch of Vertisols, though not considered suitable for their classification, does have value for assessing their potential for dryland (Table 8). The surface horizon mulches of Vertisols have lower dry bulk densities than the blocky and prismatic horizons below. This may be partly a result of the somewhat higher organic carbon content of the granular A horizons, but is mostly a result of the void space between the granules. Vertisols with these loose granular surface horizons require less energy to till and their bulk densities at 1500 kPa remain low enough so that plants can remove most of the water down to this tension.

Table 8. Some properties of granular, blocky and prismatic horizons of some Vertisols.[a]

Property[b]	Granular and fine subangular blocky	Angular medium and coarse subangular blocky	Prismatic
horizons studied	10	15	14
depth (6A1a) cm	14 (±11)[c]	31 (±16)	36 (±16)
O.C. (3A1) %	1.4 (±0.46)	0.84 (±0.45)	0.77 (±0.34)
< 2 m clay (4A1h) %	58 (±17)	51 (±9.4)	54 (±11)
bulk density dry, Mg/m^3	1.5 (±0.12)	1.7 (±0.09)	1.8 (±0.12) dry
linear extensibility (4D1) %	7.8 (±3.0)	11 (±3.5)	11 (±2.8)
linear extensibility/clay	0.14 (±0.05)	0.20 (±0.04)	0.21 (±0.03)

[a]The samples come from Arizona (2 pedons, 5 samples), California (7 pedons, 16 samples), Nevada (1 pedon, 4 samples), Hawaii (3 pedons, 5 samples), Puerto Rico (3 pedons, 7 samples), and the Virgin Islands (1 pedon, 2 samples).

[b]Codes listed below refer to methods in Soil Conservation Service (1972).

[c]The numbers are means and standard deviations of the properties.

Vertisols with these granular surface horizons should also be rated above other Vertisols without them because roots encounter less resistance to deep penetration. This results from the deep filling of cracks with surface horizon mulch during the dry season. Upon again becoming wet,

the mulch in the cracks keeps the bulk density of this area somewhat lower depending upon the strength of the granules. These cracks then become more ideal sites for root growth. As a result, these areas are the sites in which roots are most likely to locate during the next growing season. The soil again cracks behind the root as water is withdrawn. More surface mulch falls into the cracks during the next dry season and the cycle is repeated. Upon becoming wet, the previous year's mulch in the crack is compressed. After a few cycles, the density of this compressed mulch in the former crack matches that of the matrix of the prisms or blocks, but by this time the crack has become sufficiently wide to receive a fresh supply of surface mulch, thus repeating the cycle.

Agronomic practices that maintain or increase the thickness of the surface mulch should be encouraged. Peterson, in working with a Pelloxerert from California (see Nettleton et al., 1983) found that he could change the structure of the surface soil from massive to granular and then back to massive by artificially wetting it. High tension wetting-drying cycles resulted in a granular structure. Wetting samples to near saturation or puddling followed by drying, produced a massive or crusty structure.

By sprinkling, it is possible to irrigate to higher soil moisture tensions than by furrow irrigation. If higher tension can be maintained or at least followed the last cycle before cultivation, a more favorable tilth may be produced and cultivation will require less energy.

SUMMARY AND CONCLUSIONS

In this paper, we have examined moisture characteristics and tilth of Vertisols and suggested ways that the taxa may be grouped relative to their potential for cultivated crops. Regional differences occur among Vertisols in respect to the moist and the dry bulk densities and the laboratory water retention difference. The standard 33 to 1500 kPa water retention difference may not be applicable if soil roots are strongly restricted to cracks. Computation of the bulk density between cracks at intermediate water contents is presented. Roots in cracks are assumed to be restricted mechanically when the bulk density excluding the cracks reaches 1.40 Mg/m^3. The water content at this bulk density is computed and compared to the 1500 kPa retention. The 33 to 1500 kPa calculation for water retention difference has been questioned as to its applicability to many Vertisols. If one accepts that root growth is restricted at bulk densities greater than 1.4 Mg/m^3, the standard WRD can be reduced by 50% or more for Vertisols that have relatively high moist bulk density and linear extensibility. The method involves calculation of an intermediate water content (Wi) for a bulk density of the soil ped of 1.4 Mg/m^3 and a bulk density of the whole soil including crack space (Dbi) so that the water can be reported as a volume fraction.

In agronomic use of Vertisols, other things being equal, one should select those that have the thicker surface mulch. Study of pedon descriptions available to us shows these to be the Chromusterts. The Pellusterts for the most part have thinner mulches or none at all. Vertisols that

either lack a surface mulch or have a thinner one will require more careful management and possibly higher energy inputs to cultivate. If irrigation is required, sprinkle irrigation may be more satisfactory because it would make wetting to a higher tension possible offering the possibility of structure improvement.

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DISTRIBUTION AND CLASSIFICATION OF THE VERTISOLS OF THE U.S.

R. L. Guthrie and J. D. Nichols

Until about 1950, the soils now called Vertisols in the United States were generally referred to as Rendzinas (Baldwin et al., 1938). Oakes and Thorp (1951) pointed out that the concept of Rendzina in the United States was unreconcilable with its use in Europe and elsewhere. They also pointed out that the concept overlapped two orders -- azonal and intrazonal -- in the American system. The authors proposed a new Great Soil Group, Grumusols, that would include not only the Rendzinas of the United States but also the Black Cotton Soils, Regurs, and Tirs of other countries.

Vertisols as a soil name was introduced in 1960 (Soil Survey Staff, 1960) for those soils formerly called Grumusols. The formative element ert, from the Latin word verto which means turn, was chosen as the basis for a soil order that would include Grumusols of the United States and Tropical Black Clays, Black Cotton Soils, Tirs, Regurs, and Black Earths of other countries.

Distinctive features of Vertisols (Soil Survey Staff, 1975) are high clay content, high shrink-swell potential, cracks that are open to the surface at some period in most years, and either gilgai microrelief, intersecting slickensides, or wedge-shaped structural aggregates that are tilted 10° to 60° from the horizontal. Most Vertisols are dark in color, low in organic matter, and alkaline or near-neutral in reaction. The high clay content results in shrinkage and the formation of cracks when the soil dries. The cracks extend from the surface to a depth of 1 meter or more. During dry periods, when the cracks are open, soil from the surface layer often falls into the cracks. When rain returns, the soil swells and part of the soil is forced upward, resulting in the gilgai microlief and the cyclic horizonation that are characteristic of these soils. Although many of these soils have long been irrigated regularly, a distinct dry period in most years allows them to shrink, crack, and swell again as they become wet. This pattern of shrinking and swelling is typical of most Vertisols.

Vertisols occur in about 19 states (Fig. 1) of the continental United States (Soil Survey Staff, 1981). These soils are most prominent in the Blackland Prairie and Western Rio Grande Plain of Texas. This area extends from the Red River Valley on the north and northeast to the Rio Grande Plain on the southwest and the Gulf of Mexico on the south (Dudal, 1965; Templin et al., 1956; Kunze et al., 1963). Within this region, Vertisols account for more than 25% of all soils in the Western Rio Grande Plain major land resource area (MLRA) (Soil Conservation Service, 1981). They make up 10-25% of the soils in three other MLRA's in Texas: Lower Rio Grande Valley, Grand Prairie, and Gulf Coast Prairies.

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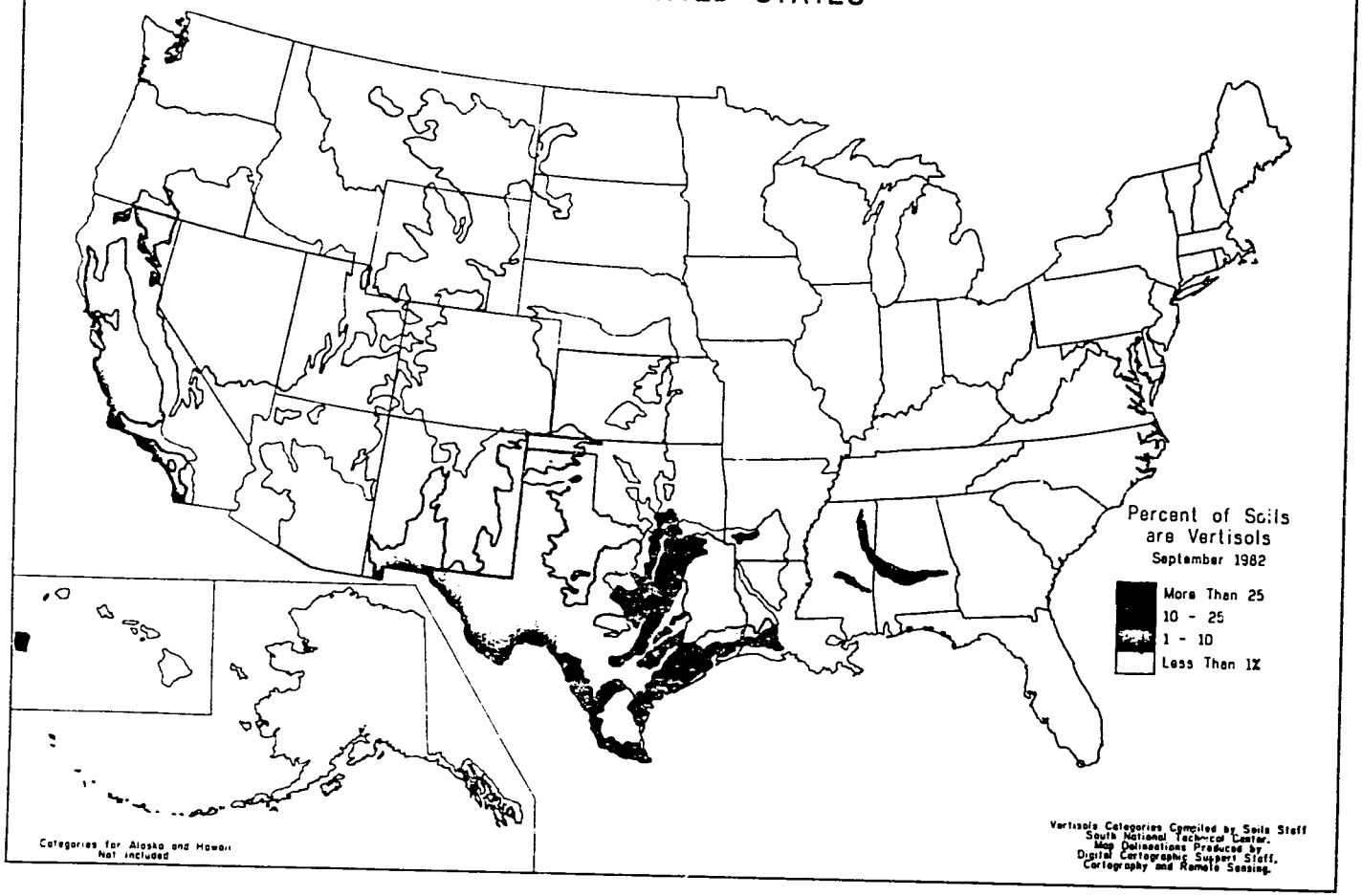
Figure 1. DISTRIBUTION AND EXTENT OF VERTISOLS IN THE UNITED STATES



Another important area of Vertisols is the Black Belt Prairie -- an 11,000 sq. km crescent that extends from northeastern Mississippi southeast across south central Alabama (Soil Survey Staff, 1981; Dixon and Nash, 1968; Rankin, 1974). Other significant areas of Vertisols are in California and New Mexico. Vertisols account for 1-10% of 14 MLRA's in Alabama, Arkansas, California, Colorado, Kansas, Louisiana, Mississippi, New Mexico, Oklahoma, Oregon, and Texas. They make up a small percentage of the soil in about 28 additional MLRA's in these and six other states.

CLIMATE

In the United States, Vertisols occur under a wide range of climatic conditions ranging from very dry to humid and very cold to hot. Except for a few areas in the northern part of the United States, the average annual soil temperature is above 8 °C (Dudal, 1965; Soil Survey Staff, 1981). With the exception of cryic, pergelic, isofrigid and isomesic soil temperature regimes, each of the soil temperature regimes recognized in Soil Taxonomy is associated with one or more soil series that are Vertisols (Beinroth et al., 1979). All of the Vertisols in the Black Belt of Alabama and Mississippi and a large proportion of those in Texas, Arizona, and California have thermic temperatures (Western Regional Soil Survey Work Group, 1964; Dixon and Nash, 1968; Kunze et al., 1963). Only the Vertisols in Hawaii and Puerto Rico have iso soil temperatures and only scattered areas in the western United States have mesic or frigid soil temperatures. Vertisols with hyperthermic temperature regimes are very extensive in Texas.

All quantitatively defined soil moisture regimes, with the exception of aquic, are represented among Vertisols in the United States. By far the most extensive regime is ustic, although many areas in California have xeric regimes. The soil moisture regime is udic in the Black Belt of Alabama and Mississippi and in extreme southeastern Texas. Small areas in other states, including Hawaii, are also udic. Small areas with an aridic moisture regime are scattered throughout the Western States. Average annual precipitation for all Vertisols of the United States ranges from less than 20 cm to more than 150 cm. All areas, including those with udic moisture regimes, have a period in most years when the soils dry and crack to a depth of 1 m or more.

TOPOGRAPHY

As in most other countries, most Vertisols in the United States have low relief (Dudal, 1965). In Texas, Vertisols with low relief occupy a long narrow strip bordering the Gulf of Mexico (Kunze et al., 1963). Vertisols on smooth erosional uplands of the Texas Blackland Prairie have moderate relief (Templin et al., 1956). In Alabama and Mississippi (Rankin, 1974), they occupy an erosional surface of low relief that is generally lower in elevation than the surrounding physiographic regions. In California most Vertisols are on hills, alluvial fans, and terraces adjacent to the San Joaquin Valley, and in Arizona they are mostly on plateaus (Western Regional Soil Survey Work Group, 1964).

Slopes of Vertisols rarely exceed 5%, although small areas in the Blacklands of Texas and in California have slopes up to 20%.

Most Vertisols in the United States formed in parent materials derived from alluvium, marl, or volcanic materials, although other kinds of parent materials are not uncommon. Most of the parent materials are fine-textured, high in calcium, and low in permeability (Templin et al., 1956; Kunze et al., 1963; Soil Survey Staff, 1975; Western Regional Soil Survey Work Group, 1964).

VEGETATION

The vegetation on most Vertisols at the time of European settlement of the United States was grass, although a few supported forests or desert shrubs (Soil Survey Staff, 1975; Rankin, 1974; Western Regional Soil Survey Work Group, 1964). Because of the savannah-like vegetation, areas of Vertisols were the first to be brought into cultivation. Difficulties with plant pests and plowing resulted in some areas reverting to grassland -- the Black Belt, for example. After 1965, however, the Black Belt entered another cycle of increased cultivation (Rankin, 1974). Most Vertisols are suited to mechanized farming and are highly productive when managed properly.

CHEMICAL AND PHYSICAL PROPERTIES

High clay content and a predominance of clay minerals with high shrink-swell potential are the most striking features of Vertisols. They must have at least 30% clay from the surface to a depth of 50 cm or more, in combination with open cracks at some time in most years.

All Vertisols are in the clayey particle size class, which for this order includes all soils with a weighted average clay content of 30% or more. With the exception of two families of Vertisols in Puerto Rico that are clayey-skeletal, all particle size families are either fine or very-fine. Approximately two-thirds of the families in each suborder have a fine particle size class, except that seven of the eight families of Terrerts are fine.

Montmorillonite is the dominant clay mineral, although there are 12 mixed families and, somewhat surprisingly, two kaolinitic families in the Usterts suborder. All the suborders contain montmorillonitic soils, and all but Xererts contain mixed families.

Combinations of fine or very-fine particle size with montmorillonitic or mixed mineralogy are not concentrated in any particular suborder, and no combination is absent from a suborder, except that there are no mixed Xererts. The largest number of families is fine montmorillonitic, followed by very-fine montmorillonitic and fine mixed. There are three very-fine mixed families and two very-fine kaolinitic families.

Some Vertisols have a large amount of exchangeable sodium and soluble salts, either alone or in combination. Some soil series in Texas have exchangeable sodium exceeding 15% and enough soluble salts to produce an electrical conductivity in the soil solution as high as 25 mmhos/cm.

Evidences of shrinking and swelling

As mentioned earlier, gilgai microrelief is external evidence of shrink-swell in many Vertisols. Internal evidence is the amplitude of waviness, especially the thickness of dark A horizons, former cracks filled with dark A horizon material, slickensides that intersect, and wedge-shaped structural aggregates (parallelepipeds).

Gilgai microrelief does not occur in all Vertisols; in some it has been obliterated by cultivation. There are two main kinds of gilgai in the United States. The dominant kind is the enclosed microbasin and microknoll type. There are some variations, especially in drier areas, where the knolls are less prominent and the microbasins are the dominant feature. In some Vertisols, the microbasins are roughly rectangular. The other kind of gilgai is the ridge and swale type. A variation of this type has discontinuous ridges.

The elevation difference in the microtopography ranges from barely perceptible to about 45 cm. Under the definition of a pedon on page 3 in Soil Taxonomy, soils with cyclic horizons are limited to linear intervals of 2-7 m and the pedon is one-half the cycle. Many soil series list the maximum distance allowable. The extreme gilgai, though, is much bigger, being as much as 22 to 28 meters across. Many Vertisols have pedons in the range of 1-3.5 m across.

The amplitude of waviness is usually measured as the thickness of the dark A horizon. In some Vertisols, especially those on floodplains, there is little amplitude of waviness. Some pedons of the Houston Black series, however, have an amplitude up to 165 cm, although 100 to 115 cm is more common. Some series are differentiated by whether they have more or less than about 36 cm amplitude of waviness.

Former cracks filled with dark material range from none to common, depending on whether the dark A horizon becomes granular enough for particles to fall into the cracks.

Slickensides that intersect are a property of all Vertisols. They range in length from a few to many centimeters. Wedge-shaped structural aggregates occur in many Vertisols at an optimum moisture content that is somewhat dry. The aggregates are usually best expressed at about 50 to 100 cm below the soil surface, although a few soils have them as shallow as 20 cm.

CLASSIFICATION

Two kinds of properties are used to differentiate Vertisols in the higher categories of Soil Taxonomy. Soil moisture differentiates suborders. It

is expressed as the number of days each year that cracks remain open or closed during most years. Color of the surface layer differentiates great groups in all suborders except Torrerts, which has an aridic moisture regime and no significant difference in surface color.

Soil moisture is an extremely limiting feature for use and management of most Vertisols. Estimates of the number of days that cracks remain open or closed were used to approximate moisture regimes, because slow permeability in association with cracks results in irregular patterns of wetting and drying. As a result of this irregular pattern, moisture retention values are difficult to measure with confidence. As Vertisols, by definition, have cracks that remain open for prescribed periods in most years, the length of these periods appeared to be a logical criterion for differentiation.

An equivalent of the aquic moisture regime was not provided for because most Vertisols assume the features of aquic soils if excess moisture is available during some period in most years. A combination of slow hydraulic conductivity and a tendency for many Vertisols to collect surface water causes most Vertisols to have the low chroma color associated with an aquic moisture regime.

Many Vertisols are saturated and even flooded for long periods in most years. Others are saturated for only short periods. Arbitrary placement of these soils in suborders based on the moisture regime of associated soils has resulted in unsatisfactory performance predictions for many soils. Additional study of soil moisture is needed, especially in tropical areas where year-long growing seasons suggest the need for refinement of the classification system, for example, by recognizing aquic Vertisols.

Difference in color of the surface layer is a useful criterion to differentiate among pedons, but surface color appears to be less well-correlated with surface configuration and slope than it was originally thought to be. Dark surface soils were thought to be associated with level or depressional landscapes on which water would be available to plants for longer periods. But dark surfaces also occur on slopes and on level landscapes where water is available only for short periods. Conversely, many light-colored surface soils occur in level landscapes where water is available to plants for long periods. Separations made only on the basis of surface color simply do not provide useful groupings for predicting performance.

The International Committee on Vertisols is studying alternative criteria for differentiae at the great group level in Soil Taxonomy. Properties associated with reaction, $CaCO_3$ content, salinity, and surface soil structure are being considered as possible differentiae because of their genetic implications and their effect on use and management.

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THE VERTISOLS OF HAWAII

H. Ikawa

ABSTRACT

The nine soil series of Vertisols in Hawaii are classified as either Torrerts, Usterts, or Uderts. They are associated with alluvial, colluvial, or residual parent materials that are derived from basic igneous rocks, primarily basalts of Pliocene and Pleistocene age. These Vertisols occur on the coastal plains and in the valleys as well as on some of the highlands where leaching of bases and silica is at minimum. The environment is characterized by a low mean annual rainfall of 500 to 900 mm and a mean annual soil temperature of 23° C. Because of the low rainfall, the vegetation includes the xerophytic shrubs and associated grasses.

The dominant soils are the Typic Chromusterts, while the others are the Entic and Udic Chromusterts, Udorthentic Pellusterts, Typic Pelluderts, and Mollic Torrerts. They belong to the very fine or fine, isohyperthermic families with the mineralogy class being either montmorillonitic, kaolinitic, or mixed. The kaolinitic or mixed family is generally associated with the Typic Chromusterts.

This study reviews the properties of several Vertisols of Hawaii and seeks the characteristics that can be used in differentiating the chrom and pell soil great groups of Vertisols. Chromusterts are well-drained, whereas the Pellustert is moderately well-drained and the Pelludert is poorly drained. The Chromusterts, furthermore, are either hard or very hard when dry and generally firm when moist. The Pellustert and the Pelludert, on the other hand, are very hard or extremely hard when dry and very firm when moist. They are all very sticky and very plastic.

Vertisols with a moist chroma of 1.5 or more in some part of the matrix of the upper 30 cm of the soil have a lower 15-bar water content than Vertisols with a moist chroma of less than 1.5. Although the dark color of Vertisols appears to be related to the presence of opaque minerals such as magnetite and ilmenite in the silt fraction rather than organic matter, this relationship does not appear to be associated with the chroma. In the Vertisols and related soils with hydromorphic properties, the kaolin minerals or mixed minerals are generally associated with the Chromusterts and the less hydromorphic soils. Montmorillonite, on the other hand, is generally the dominant mineral in the Pellusterts, Pelluderts, and the more hydromorphic soils.

Properties such as the drainage class, dry and moist consistence, 15-bar water content, and mineralogy are, therefore, some of the differentiating characteristics that may be used to distinguish the Vertisols in Hawaii having a moist chroma that are either more or less than 1.5.

INTRODUCTION

The Vertisols of Hawaii occur in the coastal plains in alluvial materials or in the long fans originating in the mountains and spreading over the coastal plains. They also occur in the valleys in colluvial as well as alluvial materials and in the uplands in residual or colluvial materials. They are mostly well-drained clayey soils and are generally nearly level or gently sloping, although a few may be moderately sloping or steep. The soil order includes most of the Dark Magnesium Clays and some of the Gray Hydromorphic Soils as classified by Cline (1955) according to the old Great Soil Group Classification System. Presently, there are nine soil series representing three suborders of Soil Taxonomy: Torrerts, Usterts, and Uderts. They occupy a land area of 12,910 hectares.

SOIL FORMING FACTORS

The alluvial, colluvial, or residual parent materials are derived from basic igneous rocks, mostly basalts, and the soils occur only on the older islands in Hawaii which range in age from two to five million years (Stearns, 1966). The common landscapes are the coastal plains and the valleys but also some of the highlands, generally where leaching of the bases and silica is not excessive. These areas have a mean annual rainfall ranging from 500 to 900 mm, although it can be as low as 450 and as high as 1100 or 1300 mm. Mean annual temperature is 23° C with a low of 20° and a high of 24° C. Vegetation is of the low rainfall areas and includes xerophytic shrubs such as the Prosopis, Leucaena, and Lantana, and grasses such as the fingergrass, the bristly foxtail, and bermudagrass (USDA, 1972).

SOIL CLASSIFICATION

The Vertisols of Hawaii are described in the soil survey report of Hawaii (USDA, 1972) and the classification of these soils is listed in Table 1. Kapuhikani soils receive only 250 to 380 mm of rainfall annually and are classified as Torrerts because they have a torric soil moisture regime and they have deep, wide cracks that remain open throughout the year. They are further classified as Mollic Torrerts because of their dark brown surface horizon.

Kaena soils occur in areas of mean annual rainfall ranging from 760 to 1100 mm. With a udic soil moisture regime, their cracks remaining open for less than 90 days each year, they are classified as Uderts. Because of the low chroma of less than 1.5 when moist and because of the mottled horizons, they are further classified as Typic Pelluderts.

The other seven soil series have a ustic soil moisture regime and are classified as either Chromusterts or Pellusterts. Chromusterts have chromas of 1.5 or more when moist, while Pellusterts have chromas of less than 1.5. Waihuna, Honouliuli, Lualualei, and Makalapa soils are classified as Typic

Table 1. Classification of the nine Vertisols of Hawaii according to Soil Taxonomy, FAO legend, and French Taxonomy (USDA, 1981; Beinroth et al., 1979).

Soil series	Area[a]	U. S. Soil Taxonomy		FAO	French Taxonomy
	ha	Subgroup	Soil family	Soil unit	Subgroup[b]
Kapuhikani	506	Mollic Torrerts	very-fine, montmorillonitic, isohyperthermic	Chromic Vertisols	III/211
Kaena	1684	Typic Pelluderts	very-fine, montmorillonitic, isohyperthermic	Pellic Vertisols	III/211
Waihuna	1791	Typic Chromusterts	very-fine, kaolinitic, isothermic	Chromic Vertisols	III/111
Honouliuli	1423	Typic Chromusterts	fine, mixed, isohyperthermic	Chromic Vertisols	III/111
Lualualei	5094	Typic Chromusterts	very-fine, montmorillonitic, isohyperthermic	Chromic Vertisols	III/111
Makalapa	1192	Typic Chromusterts	very-fine, montmorillonitic, isohyperthermic	Chromic Vertisols	III/211
Nonopahu	356	Entic Chromusterts	very-fine, kaolinitic, isohyperthermic	Chromic Vertisols	III/211
Papaa	455	Udic Chromusterts	very-fine, montmorillonitic, isohyperthermic	Chromic Vertisols	III/211
Kokokahi	409	Udorthentic Pellusterts	very-fine, montmorillonitic, isohyperthermic	Pellic Vertisols	III/111
Total	12910				

[a]As reported by H. H. Sato, SCS, USDA (Honolulu). Total land area of Hawaii is 1,665,400 ha.

[b]III/111 is sous-groupe model of groupe des vertisols a drainage externe nul ou reduit a structure arrondie; III/211 is sous-groupe model of groupe des vertisols à drainage externe possible à structure arrondie.

Chromusterts. Nanopahu soils, on the other hand, are called Entic Chromusterts because they grade to Entisols, while Papaa soils are Udic Chromusterts because they have a more moist moisture regime than the Typic Chromusterts. Kokokahi soils are classified as Udorthentic Pellusterts because they are more moist and are younger than the Typic Pellusterts.

As indicated in Table 1, the Vertisols of Hawaii have either a montmorillonitic, kaolinitic, or mixed mineralogy class. The kaolinitic and mixed families include not only kaolinite but also halloysite, X-ray amorphous materials, as well as montmorillonite (R. C. Jones, personal communication). Because of the high clay content, these soils belong to the fine or very-fine particle size class. Their mean annual soil temperature, furthermore, is above 22° C, and because the difference between the mean summer and mean winter temperatures is less than 5° C, they belong to the isohyperthermic temperature class. The exception is the Waihuna soil which is isothermic.

Soil parent materialss determine the kind of mineralogy (Uehara and Sherman, 1956; Ruhe et al., 1965). For example, the alkaline coastal plain sediments having low iron and manganese oxide content but appreciable calcium carbonate are dominated by 2:1 lattice clay. The acidic highland materials having higher oxide content are dominated by kaolinitic clay. The materials occupying the landscapes between the coastal plains and the highlands are in turn made up of montmorillonitic as well as kaolin minerals.

Pedogenic processes operating in the soils also influence the mineralogy of soils (Hussain and Swindale, 1970). With the influx of colloids and ions of silicon, iron, aluminum, and the bases into the lower soil horizons with a water table, kaolin minerals such as halloysite may resilicate to montmorillonite. There is also evidence that when the activity of iron in the soil solutions is sufficiently high, montmorillonite may transform to nontronite or a nontronitic mineral (Hussain and Swindale, 1970; Sherman et al., 1962). The montmorillonites of Hawaii, therefore, have not only high magnesium content, reflecting the release of that ion from decomposing olivine, but also a high iron content. The occurrence of hydrated halloysite is attributed by Hussain and Swindale to moist conditions and less frequent wetting and drying cycles with increasing soil depth.

DISCUSSION ON SOIL CLASSIFICATION

Moist chroma and classification

According to Soil Taxonomy (USDA, 1975), chroma is used to differentiate (1) Chromusterts from Pellusterts and (2) Chromuderts from Pelluderts. Both Chromusterts and Chromuderts have a chroma, moist, of 1.5 or more in some part of the matrix of the upper 30 cm in more than half of each pedon. Chromusterts and Chromuderts are further described as having gentle slopes where water cannot stand. On the other hand, the Pellusterts and Pelluderts (most of them) are described as being level or in depressions. Such statements imply that Chromusterts and Chromuderts are better drained soils than Pellusterts and Pelluderts.

Although soil inclusions are to be expected within a soil map unit, for example, Pellusterts within Chromusterts, one of the problems in classifying Vertisols is separating the chrom group from pell group based on chroma.

In Venezuela, Comerma and Luque (1982) also found some difficulty in separating their Chromusterts from Pellusterts using the present definition of Vertisols in Soil Taxonomy. They obtained a satisfactory separation only after using a chroma of 2 or less to differentiate the poorly drained from the better drained soils.

It is probable that the problem is also in using the Munsell Soil Color Charts. Although most of the Vertisols of Hawaii have been recorded with a hue of 10YR (USDA, 1972), there are others that have been recorded with hues of 5YR and 7.5YR. The 5YR and 10YR hue pages do not appear to present a problem because the chromas are in increments of 1, 2, 3, 4, 6, and 8. On the other hand, the 7.5YR and 2.5Y hue pages have chromas in increments of 0, 2, 4, 6, and 8. It appears that there may be difficulties in recording the soil color when the chroma is between 0 and 2.

The dark color in black soils has been reviewed by Sherman and Uehara (1956) and Uehara and Sherman (1956). Iron oxide and humus including sodium or magnesium-dispersed organic matter were cited as some of the causes of the black color. Based on their observation, Sherman and Uehara, however, believed that organic matter may not be the cause of the color in black tropical soils. They found black montmorillonitic clays (1) under protected areas of basalt rocks where conditions favored the retention of bases and (2) within the basalt rocks where there was decomposition of olivine crystals. In both cases, little or no organic matter was present. Uehara and Sherman (1956) further concluded that in the red and black complex soils of Hawaii, kaolin was the dominant mineral in the red soils and montmorillonite was the dominant mineral in the black soils.

Montmorillonite was identified in the dark-colored, poorly drained, sticky and plastic Gray Hydromorphic Soils of Hawaii by Gill and Sherman (1952). For these soils, percent organic matter and cation exchange capacity of the soil was found to be highly correlated with plasticity. These authors attributed the plastic properties not only to the clay type and organic matter content but also to adsorbed cations such as magnesium. They found that these soils became dispersed and plastic when the percent magnesium saturation exceeded 30 percent in the presence of organic matter, providing the ratio of exchangeable calcium to exchangeable magnesium was approximately unity. The Vertisols and related soils of Hawaii have a high magnesium content because they are derived from basic igneous rocks such as olivine basalt (Cline, 1955).

Selected studies of some Vertisols and related soils

A discussion is made to show the difference existing in the Vertisols of Hawaii and to seek the differentiating characteristics of the chrom and pell soil great groups in Hawaii.

Study of SCS. Six Chromusterts are described in the soil survey report of Hawaii (USDA, 1972). In addition, the laboratory data of three of these Chromusterts are reported by the SCS (USDA, 1976). Examination of the soil descriptions shows that four of the Chromusterts are well-drained, while two others are either moderately well-drained or well-drained. The Pellustert is moderately well-drained while the Pelludert is poorly drained. Further examination of the soil descriptions (USDA, 1972) reveals that the consistence of the six Chromusterts in the upper 30 cm of the soil are either hard or very hard when dry and generally firm when moist. On the other hand, the Pellustert is very hard to extremely hard when dry and very firm when moist, while the Pelludert is extremely hard when dry and very firm when moist. All of the soils except one were described as being very sticky and very plastic.

These descriptions thus show that in general Pellusterts and Pelluderts in Hawaii are less well-drained than the Chromusterts and have extremely hard and very firm consistence.

Descriptions of the Lualualei clay, a montmorillonitic Chromustert, and the Waihuna clay, a kaolinitic Chromustert, are presented as follows, with their respective laboratory data in Tables 2 and 3 (USDA, 1976).

Description of Lualualei clay

Horizon	Description
A11	0 to 3 cm; very dark gray (10YR 3/1) clay; very dark grayish-brown (10YR 3/2) dry; strong fine and very fine granular structure; very hard, firm, very sticky, very plastic; many fine roots; few light-colored sand grains; vertical cracks up to 5 cm wide; strong effervescence with hydrogen peroxide; neutral (pH 7.1); abrupt smooth boundary.
A12	3 to 25 cm; very dark gray (10YR 3/1) clay; very dark grayish-brown (10YR 3/2) dry; moderate coarse prismatic structure breaking to moderate medium subangular blocky structure; very hard, firm, very sticky, very plastic; many fine roots; many fine tubular pores; some organic litter within the cracks; strong effervescence with hydrogen peroxide; neutral (pH 7.2); gradual smooth boundary.
AC	25 to 55 cm; very dark grayish-brown (10YR 3/2) clay; very dark grayish-brown (10YR 3/2) dry; moderate coarse prismatic structure breaking to moderate medium subangular blocky structure; very hard, firm, very sticky, very plastic; many fine roots; many fine tubular pores; common slickensides; few black specks; few grains of coral sand; strong effervescence with hydrogen peroxide; neutral (pH 7.2); clear smooth boundary.
C1	55 to 75 cm; very dark grayish-brown (10YR 3/2) clay; very dark grayish-brown (10YR 3/2) dry; moderate medium and coarse subangular blocky structure; many weakly grooved slickensides; hard, firm, very sticky, very plastic; common fine and medium roots mainly matted between cleavage plains; few fine and very fine tubular pores; common black stains in pores and in dendritic pattern on ped faces; few light-colored sand grains; common shiny specks; strong effervescence with hydrogen peroxide; neutral (pH 6.8); gradual smooth boundary.

Table 2. Laboratory data of Lualualei clay; Typic Chromustert, very-fine, montmorillonitic, isohyperthermic.

Depth	Horizon	Particle size analysis sand 2-.05	silt .05-.002	clay .002	Bulk density	Water content .3-bar	15-bar	Organic C	Total N	C/N	Extractable Fe
(cm)		(% of 2mm)			(g/cc)	(%)		(%)	(%)		(%)
0-3	A11				1.29	31.8	22.0	0.66	0.082	8	7.3
3-25	A12				1.38	30.0	22.1	0.42	0.060	7	7.0
25-55	AC				1.52	28.4	22.7	0.21	0.054	4	7.5
55-75	C1				1.56	27.8	21.4	0.17	0.044	4	7.3
75-123	C2cs				1.54	28.4	22.3	0.17			6.6

Depth	Exchangeable bases Ca	Mg	Na	K	Sum	Cation exch. capacity	Base saturation	pH H_2O	KCl	Extensibility COLE
(cm)	(meq/100 g)						(%)			(cm/cm)
0-3	17.1	15.2	0.8	1.4	34.5	34.1	100+	7.1	5.9	
3-25	15.1	15.1	1.3	0.4	31.9	32.9	97	7.2	5.4	
25-55	14.6	13.4	2.5	0.2	30.7	32.9	93	7.2	5.4	
55-75	16.0	10.5	3.9	0.2	30.6	32.1	95	6.8	5.2	0.136
75-123	73.1	9.3	7.2	0.2		29.8		5.6	4.9	

Remarks: bulk density is field moist; cation exchange capacity is by NH_4OAc. Source: USDA, SCS (1976), p. 202.

Table 3. Laboratory data of Waihuna clay; Typic Chromustert, very-fine, kaolinitic, isothermic.

Depth	Horizon	Particle size analysis sand 2-.05	silt .05-.002	clay .002	Bulk density	Water content .3-bar	15-bar	Organic C	Total N	C/N	Extractable Fe
(cm)		(% of 2 mm)			(g/cc)	(%)		(%)	(%)		(%)
0-10	Ap1				1.15	34.3	26.6	1.11	0.13	9	9.1
10-43	Ap2				1.19	35.6	28.9	1.51	0.17	9	9.1
43-58	B21				1.28	35.5	29.4	0.40	0.08	5	9.4
58-93	B22				1.23	36.5	30.8	0.29			9.7
93-135	B23				1.18	36.9	31.4				9.9
135-163	B24				1.28	35.5	30.2				9.5

Depth	Exchangeable bases Ca	Mg	Na	K	Sum	Cation exch. capacity	Base saturation	pH H_2O	KCl	Extensibility COLE
(cm)	(meq/100 g)						(%)			(cm/cm)
0-10	8.9	3.7	0.2	0.6	13.4	20.0	67	5.0	4.0	0.078
10-43	6.4	2.4	0.1	0.5	9.4	22.8	41	4.5	3.6	0.071
43-58	9.5	4.9	0.2	1.3	15.9	20.4	78	5.9	5.0	0.045
58-93	8.3	7.6	0.4	1.0	17.3	19.8	87	6.0	5.1	0.049
93-135	3.6	7.8	0.5	0.3	12.2	18.0	68	4.7	3.6	0.043
135-163	5.3	8.6	0.5	0.4	14.8	19.4	76	4.8	3.7	0.042

Remarks: Bulk density is at 1/3-bar; cation exchange capacity is by NH_4OAc. Source: USDA, SCS (1976), p. 198.

Horizon	Description
C2cs	75 to 123 cm; very dark grayish-brown (10YR 3/2) clay; very dark grayish-brown (10YR 3/2) dry; strong medium and coarse subangular blocky structure; many deeply grooved slickensides; hard, firm, very sticky, very plastic; few fine roots matted between ped faces; few fine tubular pores; many fine and medium gypsum crystals; common black stains in pores and on peds; common shiny specks; few light-colored sand grains; strong effervescence with hydrogen peroxide; medium acid (pH 5.6); abrupt smooth boundary.
C3cs	123 cm; very dark grayish-brown (10YR 3/2); very dark grayish-brown (10YR 3/2) dry; strong coarse subangular blocky structure; many deeply grooved slickensides; extremely hard, very firm, very sticky, very plastic; few fine roots between peds; few fine tubular pores; common medium and coarse gypsum crystals; few shiny specks; strong effervescence with hydrogen peroxide; medium acid (pH 5.8).

Description of Waihuna clay

Horizon	Description
Ap1	0 to 10 cm; dark brown (7.5YR 3/3) clay; moderate very fine and fine granular structure; very hard, friable, very sticky, very plastic; common plant remains that have been plowed under; many interstitial pores; violent effervescence with hydrogen peroxide; clear smooth boundary.
Ap2	10 to 43 cm; dark brown (7.5YR 3/3) clay; structureless (massive); very hard, slightly friable, very sticky, very plastic; common plant remains that have been plowed under; common pores; violent effervescence with hydrogen peroxide; common variegated sand grains can be seen under hand lens; clear smooth boundary.
B21	43 to 58 cm; dark brown (7.5YR 3/3) clay; weak and moderate very fine subangular blocky structure; friable, very sticky, very plastic; few roots; common pores; many variegated sand grains can be seen under hand lens; violent effervescence with hydrogen peroxide; clear wavy boundary.
B22	58 to 93 cm; dark brown (7.5YR 3/2) clay; moderate very fine and fine subangular blocky structure; friable, very sticky, very plastic; no roots; many very fine and fine tubular pores; many manganese stains and concretions; common thin patchy glaze; crushed color has slightly higher chroma; many variegated sand grains; occasional highly weathered pebbles; strong effervescence with hydrogen peroxide; gradual wavy boundary.
B23	93 to 135 cm; dark brown (7.5YR 3/2) silty clay; weak medium prismatic breaking into strong fine and medium subangular blocky structure; friable, very sticky, and very plastic; no roots; many very fine tubular pores; many variegated sand grains can be seen under the hand lens; few highly weathered pebbles; many manganese stains and concretions; manganese stains are mainly on cleavage planes;

Horizon	Description
	common thin patchy glaze; few pressure cutans; slight effervescence with hydrogen peroxide except on manganese stains and concretions where it is violent; gradual wavy boundary.
B24	135 to 163 cm; dark brown (7.5YR 3/2) silty clay; strong medium and coarse subangular blocky structure breaking into weak very fine and fine subangular blocky structure; friable, very sticky, very plastic; no roots; common very fine tubular pores; many variegated sand grains can be seen under a hand lens; many manganese stains and concretions; continuous thin glaze on ped surfaces; many slickensides, occasional highly weathered pebbles; slight effervescence with hydrogen peroxide except on manganese stains and concretions where it is violent.

Study of Raymundo. Six Vertisols are also reported by Raymundo (1965). Although he has used various numbers and names to identify these soils, they are located mostly in areas currently mapped as Chromusterts. Because his soil descriptions indicate neither the drainage class nor the relationship between the moist chroma and the dry and moist consistence, no comparison can be made with the relationships observed for the SCS study. The soil profiles of Raymundo, however, are of interest in this study because three of them have a moist chroma of 1.5 or more in the major part of the matrix of the upper 30 cm of the soil, while three others have a moist chroma of less than 1.5. Presumably, they are Chromusterts and Pellusterts, respectively. Seventeen of the upper two or three horizons were selected from these soils and grouped according to chroma, and they are presented in Table 4.

It is interesting to note that the mean 15-bar water content was 27.4% for the eight horizons with a moist chroma of 1.5 or more and 35.8% for the nine horizons with a moist chroma of less than 1.5.

A correlation analysis of Raymundo's data of the two groups of horizons showed a highly significant negative relationship between chroma and 15-bar water content ($r = -0.780$) and between chroma and cation exchange capacity ($r = -0.627$), where $r = 0.606$ at the 1% level of significance (d.f. = 15). The low chroma is, therefore, associated with a high 15-bar water content and a high cation exchange capacity. A high 15-bar water content and a high cation exchange capacity are in turn related to the presence of minerals such as montmorillonite or even X-ray amorphous materials.

Table 4 shows that montmorillonite tended to be more abundant than kaolinite in the group of soil horizons having the low chroma. Because montmorillonite has a higher cation exchange capacity than the kaolin minerals, Table 4 supports the statement relating montmorillonite to the high cation exchange capacity in the correlation analysis.

Of the seven pedons of Chromusterts reported by the SCS (USDA, 1976), 13 of the horizons in the upper 30 cm of the soil have a chroma of more than 1.5, with two horizons being less than 1.5. The 13 horizons show a mean 15-bar water of 27.5%, a value which is very similar to the mean value of 27.4% for Raymundo's soils having a moist chroma of more than 1.5.

Raymundo (1965) suggests that the dark color of his Vertisols are related more to opaque minerals such as magnetite and ilmenite in the silt fraction rather than to organic matter. There is, however, no significant relationship between chroma and the chemical constituents of these minerals, the Fe_2O_3 and TiO_2 contents. According to W.A. Blokhuis (personal communication), the dark colors are related more to value than to chroma. Nevertheless, Raymundo's study strongly suggests a relationship between the dark color and the presence of the opaque minerals, and there is a need to pursue the color relationship still further.

Raymundo's data, thus, indicate that a low chroma is associated with a high 15-bar water content and minerals with high cation exchange capacity, minerals such as montmorillonite and even amorphous materials.

Study of Hussain and Swindale. A group of six imperfectly to poorly drained soils formerly classified as Gray Hydromorphic Soils was studied by Hussain and Swindale (1970). Presently, one soil is classified as a Typic Chromustert, two as Typic Tropaquept, two as Typic Calciaquoll, and another as Cumulic Haplaquoll.

Although only one of the soils is a Vertisol, all of the data were examined to see if there were any relationship between moist chroma and properties relating to hydromorphic characteristics. Hussain and Swindale found little variation in the hues and values of the epipedons throughout the hydromorphic sequence. Furthermore, the chromas of the epipedons did not decrease with increasing wetness. In fact, all of the epipedons above the 10 cm depth, except for one soil, had a chroma of 2 or 3 and there was no relation between chroma and the 15-bar water content that was observed in the data of SCS (USDA, 1976) and of Raymundo (1965).

The general trend in the study of Hussain and Swindale (1970), however, was that as the soils became hydromorphic, soil color values increased and structures deteriorated. Whereas, halloysite was the dominant clay mineral in the less hydromorphic soils (the Chromusterts), montmorillonite was dominant in the more hydromorphic soils. Hydrated halloysite was present in all of the soils, but it was most abundant in the more hydromorphic soils.

Differentiating characteristics in Vertisols of Hawaii

The nine soil series of Vertisols in Hawaii are classified as Torrerts, Usterts, and Uderts. For the Usterts and Uderts, a moist chroma of 1.5 is used to differentiate the Chromusterts from Pellusterts and the Chromuderts from Pelluderts.

The review of literature showed that, in general, the Chromusterts of Hawaii are well drained, while the Pellustert is moderately well drained and the Pelludert is poorly drained. The Chromusterts have either a hard or very hard and generally a firm consistence, but the Pellusterts and Pelluderts have a very hard to extremely hard and very firm consistence.

Vertisols with epipedon having a moist chroma of 1.5 or higher have a lower 15-bar water content than those having a lower chroma. In Hawaii, the former soils include the Chromusterts and are associated with a kaolinitic or mixed mineralogy class. The latter soils include the Pellusterts and the

Table 4. Laboratory data of selected 17 horizons of Vertisols reported by Raymundo (1965).

Soil	Depth	Chroma	Clay	Bulk density	15-bar water	Organic carbon	Exchangeable bases				CEC	pH	
							Ca	Mg	Na	K		H_2O	KCl
	(cm)		(%)	(g/cc)	(%)	(%)	(meq/100 g)						
2	0-5	1	78.1	1.8	37.6	0.65	66.6	30.9	2.6	3.7	91.4	7.8	6.5
2	5-13	1	77.0	1.4	35.5	0.63	70.3	40.3	1.7	2.1	90.4	7.8	6.6
3	0-10	1	58.1	1.6	36.4	0.55	53.2	25.8	1.9	1.3	81.8	7.8	6.2
3	10-25	1	49.7	1.5	36.2	0.46	50.4	22.7	4.4	1.0	82.2	8.1	6.4
3	25-61	1	52.4	1.7	36.7	0.40	49.2	23.8	7.7	0.8	83.6	8.1	6.6
4	15-76	1	75.8	1.7	31.7	0.56	23.4	25.7	7.4	0.9	60.6	6.6	5.8
5	0-10	1	59.2	1.6	34.6	0.93	27.6	23.0	5.7	1.6	60.9	7.4	6.3
5	10-36	1	68.1	1.7	37.8	0.57	23.3	20.4	9.9	0.9	68.6	7.7	6.6
1	0-5	2	70.6	1.7	27.0	1.27	34.9	18.7	1.5	5.2	50.9	6.7	6.2
1	5-15	2	67.8	1.7	25.5	0.78	37.6	17.5	1.1	1.5	52.8	7.4	6.4
1	15-30	2	64.3	1.8	26.1	0.58	40.7	18.6	1.8	0.7	51.1	7.7	6.4
2	13-51	2	73.3	1.6	34.7	0.48	65.2	15.7	2.4	1.3	85.4	8.1	6.6
4	0-5	2	71.6	1.6	34.2	0.88	24.5	29.6	5.0	1.6	54.5	7.1	5.9
4	5-15	2	76.1	1.7	20.6	0.67	24.8	24.5	6.1	1.1	59.2	7.0	5.9
6	0-10	2	59.1	1.7	27.9	0.78	17.5	21.0	1.5	1.3	61.8	5.8	4.4
6	10-25	2	50.3	1.6	26.8	0.77	18.2	26.0	2.4	1.1	65.0	6.2	5.6
6	25-46	2	36.8	1.6	23.4	0.39	18.8	31.1	7.6	0.9	59.1	6.0	4.7

Table 4. (Continued).

Soil	Depth (cm)	Chroma	Total Elemental Analysis SiO_2	TiO_2	Fe_2O_3	MnO	MgO (%)	CaO	Na_2O	K_2O	P_2O_5	Mineralogy class[a] Mont.	Kaol.
2	0-5	1	47.3	3.9	15.4	0.25	3.62	4.54	0.45	0.58	0.08	3X	1X
2	5-13	1	46.9	3.6	15.4	0.25	3.76	4.82	0.45	0.48	0.76	3X	1X
3	0-10	1	42.4	5.8	19.0	0.67	3.84	2.20	0.65	0.67	0.66	3X	2X
3	10-25	1	43.7	5.9	19.9	0.69	2.94	2.67	0.73	0.63	0.58	3X	2X
3	25-61	1	42.9	6.4	19.6	0.65	2.83	2.43	0.77	1.13	0.62	3X	2X
4	15-76	1	43.4	3.4	18.2	0.65	1.67	1.75	0.87	0.32	0.57	3X	1X
5	0-10	1	47.0	2.9	15.1	0.34	3.42	5.32	1.07	0.32	0.71	3X	1X
5	10-36	1	47.7	2.9	15.7	0.36	2.09	4.11	1.27	0.29	0.68	3X	1X
1	0-5	2	36.3	4.6	19.2	0.51	2.97	3.27	0.44	0.54	1.08	3X	2X
1	5-15	2	39.8	4.6	19.1	0.48	2.71	3.63	0.47	0.35	0.94	3X	2X
1	15-30	2	40.0	4.8	19.7	0.45	2.47	4.15	0.40	0.27	0.92	3X	2X
2	13-51	2	49.4	3.2	15.0	0.28	2.45	5.44	0.44	0.53	0.89	3X	1X
4	0-5	2	41.4	4.2	18.1	0.58	3.79	2.52	0.51	0.27	0.60	3X	1X
4	5-15	2	42.7	3.6	17.4	0.59	2.09	2.02	0.64	0.28	0.59	3X	1X
6	0-10	2	50.1	3.0	15.5	0.24	1.52	1.36	0.94	0.24	0.41	2X	2X
6	10-25	2	54.0	3.1	12.4	0.29	1.95	2.35	1.46	0.29	0.46	2X	2X
6	25-46	2	52.8	2.2	13.8	0.33	3.42	3.76	1.34	0.58	0.34	2X	2X

[a]Mont. = montmorillonite; kaol. = kaolinite. Amounts: 1X = trace to small; 2X = moderate; 3X = large.

Pelluderts and are associated with a montmorillonitic mineralogy class. Studies with hydromorphic soils have also shown that halloysite was the dominant mineral in the less hydromorphic soils and montmorillonite was the dominant mineral in the more hydromorphic soils.

Indications are that the dark colors of Vertisols are more related to the presence of opaque minerals such as magnetite and ilmenite in the silt fraction rather than organic matter. This relationship, however, does not appear to be associated with the chroma.

This study, therefore, suggests that Vertisols of Hawaii having a moist chroma of 1.5 or more can be differentiated from those with a lower chroma. The differentiating characteristics are drainage class, dry and moist consistence, 15-bar water content, and mineralogy which includes the amount of montmorillonite and amorphous materials.

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ACID VERTISOLS OF TRINIDAD

N. Ahmad

INTRODUCTION

Typically, Vertisols are derived from rocks and other parent materials which yield abundant cations and essentially clay residues on weathering. Since they also usually occur in climates with a distinct dry season, some of the released cations, particularly Ca and Mg, accumulate in the solum with the result that montmorillonite clays are synthesized *in situ*. It is properties of this mineral that largely determine the behavior of the re-resulting soils.

Increasingly, Vertisols are recognized that are essentially acid. This was acknowledged by Smith (1982 and personal communication) as a result of his experiences in the Caribbean and Venezuela in the 1970's and Ahmad (1980). The general recommendation was that official recognition should be given to the occurrence of acid families of the various suborders of Vertisols, the limits between acid and nonacid members being set at pH 5 (water) and pH 4.5 (KCl).

If these limits are acceptable, over 25% of Trinidad consists of acid Vertisols; a listing of the more typical ones is shown in Table 1.

OCCURRENCE AND GENESIS OF ACID VERTISOLS

On the coast of South America, the Caribbean Islands, Central America, the southern United States, and possibly in other parts of the tropics and subtropics in essentially wet climates, acid Vertisols occur on fine-textured sediments; these have been derived from previously weathered and altered materials in a regime that favored the synthesis of montmorillonite. The clay texture and montmorillonite mineralogy of the resulting soils are, therefore, directly inherited from their parent materials. Where these deposits are of recent age, they usually occur on coastal fringes, estuarine conditions and river floodplains and have an essentially flat topography of less than 1% slope. They are subject to tidal and/or wet season flooding and to continuous leaching.

Acid Vertisols also develop on geologically older materials, providing these are secondary in origin and have been subject to at least one former cycle of weathering. Thus, in Trinidad there is a large area in the central and southern parts of the island of noncalcareous lacustrine deposits of Pliocene to Eocene age, which is now elevated and dissected. On this location, two of the most widespread acid Vertisols of Trinidad have developed. The present floodplains of rivers draining this area also have acid Vertisols which are derived as products of erosion from these older deposits.

Table 1. Acid Vertisols of Trinidad - their classification, parent materials, aerial extent and pH range.

Series	Family	Sub-group	Parent material	Aerial extent (ha)	pH range (water)
Bejucal clay	very fine, mixed	Entic Pelluderts	swamp clay	2,335	4.6 - 4.7
Biche clay	very fine, mixed	Aquentic Chromuderts		724	
Buenos Ayres savanna clay	very fine, mixed	Entic Pellusterts	clay shale	200	4.6 - 5.2
Cacandee clay	very fine, montmorillonite	Typic pelluderts	swamp clay	886	4.0 - 5.0
Cedros clay	very fine, mixed	Entic Chromusterts	sandy clay shale	467	5.0 - 5.6
Columbia clay	very fine, mixed	Udic Chromusterts	clay alluvium	125	4.1 - 5.4
Cromarty clay	very fine, mixed	Entic Pelluderts	clay alluvium	7,155	5.0 - 5.7
Debe clay	very fine, mixed	Entic Pelluderts	clay alluvium	2,324	3.9 - 4.8
EcclesVille clay	very fine, mixed	Aquentic Chromuderts	clay shale	34,506	4.6 - 4.9
La Brea clay	very fine, mixed	Entic Chromusterts	clay shale	240	4.1 - 5.5
La Fortune clay	very fine, mixed	Entic Pelluderts	swamp clay	1,956	4.7 - 5.0
La Retraite clay	very fine, mixed	Udorthentic Chromusterts	clay shale	3,798	4.8 - 5.0
Marac clay	very fine, mixed	Udorthentic Chromusterts	clay shale	3,800	5.0 - 5.2
San Francique clay	very fine, mixed	Entic Pelluderts	swamp clay	5,427	4.2 - 5.0
Talparo clay	very fine, mixed	Aquentic Chromuderts	clay shale	65,227	4.3 - 4.7

The transported sediments need not be rich in montmorillonite at their source. In many instances during transport and aqueous contact over long periods of time, changes could take place which eventually result in considerable montmorillonite being formed. An important example of this change is the case of the Amazon-derived sediments which are deposited on the coast of South America, particularly Guyana and Suriname. These sediments which originated from the Andes Mountains and other mountainous areas of South America are initially rich in micas. In long contact with the fresh waters of rivers, partial weathering of these minerals takes place. These altered sediments eventually come into contact with marine salts in the ocean as they are swept along the South American coast. When they are finally deposited on the fore-shore, they have considerable montmorillonite and the derived soils consequently develop vertic properties.

Some acid Vertisols of Trinidad and those of Venezuela (J. Comerma, personal communication) (G.D. Smith, personal communication) and Guyana are submerged for several months each year in the wet seasons. In the dry seasons they dry out and crack deeply even though the subsoils may be quite wet. In these cases, the top soil is invariably dark grey in color and the subsoil could range in color from essentially grey to weakly mottled yellowish-red. At greater depth, the profiles are uniformly gleyed.

PROPERTIES OF ACID VERTISOLS

Particle-size distribution and basic chemical properties of representative acid Vertisols of Trinidad are presented in Table 2. In Table 3, data showing the chemical properties in field conditions (extractions by neutral normal KCl and NH_4 Cl) are presented. Not all of the acid Vertisols of the region have been studied mineralogically, but the limited studies which were done are summarized in Table 4. From the data, and from other field observations, the following points could be made:

Texture and structure

Vertisols are by nature fine-textured; however, the acid members, being derived from water-transported sediments already of clay size, are particularly fine-textured. Many of the Trinidad examples have clay contents higher than 90% in the subsoils; although an estimate for fine clay ($<0.2\mu$) is not yet available for the Trinidad soils, fine clay in a Guyana acid Vertisol is more than twice that of a coarse clay (Ahmad et al., 1962). Therefore, these soils are extremely fine-textured; this has implications for their agricultural use. The clays are easily dispersed and the soils accordingly have extremely low hydraulic conductivities.

The structural features of the acid Vertisols are for the most part typical of the order. Variations occur depending upon the duration and extent of inundation in the wet seasons for those that are so affected. Some could have an appreciable amount of organic matter in the surface layer to the extent where this could ameliorate the deficiencies of structure. In such cases, the soil could have a friable surface structure with typical vertic features at depth. In the most extensive soil in Trinidad, the Talparo clay,

Table 2: Particle-size distribution and chemical properties of some acid Vertisols of Trinidad.

Depth(cm)	pH[a]	Mechanical analysis[b] %Oven dry soil				m.e. per 100 gm. oven dry soil[c]						% Base Sat.	%Oven dry soil		C/N Ratio	p.p.m. (Truog)
		Coarse Sand 2-.2mm	Fine Sand .2-.02 mm	Silt .02-.002 mm	Clay <0.002 mm	C.E.C.	T.E.B.	Ca	Mg	K	Na		C	N		
Bejucal clay																
0 - 12	4.7	0	7	12	83	20.3	6.0	2.4	3.1	0.71	0.43	30	4.7	0.37	12.7	12
12 - 35	4.7	0	7	12	83	20.3	6.0	2.4	3.1	0.71	0.43	30	4.7	0.37	12.7	12
35 - 51	4.7	0	3	12	87	22.6	6.9	3.4	3.5	0.81	1.01	31	3.7	0.35	10.6	11
51 - 107	4.6	0	2	7	92	21.6	4.0	0.9	3.9	0.04	0.78	19	-	-	-	9
107 - 167	4.7	0	2	7	91	24.6	5.3	0.2	4.5	0.10	0.94	22	-	-	-	6
	4.7	0	4	7	89	25.9	6.9	0.4	6.8	0.04	1.18	27	-	-	-	3
Debe clay																
0 - 7.5	4.8	0	1	13	83	24.1	11.1	15.0	5.9	0.58	2.12*	88	2.3	0.29	7.9	16
7.5 - 25	4.9	2	2	13	85	23.5	28.4	13.5	6.5	0.30	2.21*	78	0.7	0.14	5.0	10
25 - 60	4.5	3	3	13	85	24.6	11.8	8.0	5.5	0.26	3.20*	48	0.5	0.10	5.0	6
60 - 95	4.3	2	3	13	89	23.6	10.1	7.2	5.7	0.25	4.35*	43	-	-	-	7
95 - 145	4.1	1	3	6	93	21.4	12.6	7.0	7.5	0.34	4.42*	-	-	-	-	6
La Retraite clay																
0 - 10	5.0	1	30	19	43	18.2	15.5	9.7	5.8	0.99	0.55	85	3.0	0.33	9.1	19
10 - 25	4.8	1	26	13	62	21.5	9.8	6.9	2.5	0.75	0.40	46	1.2	0.18	6.7	6
25 - 65	4.8	1	26	17	63	21.8	7.9	3.1	4.7	0.42	0.50	36	-	-	-	Trace
65 - 110	5.1	1	23	15	64	22.6	11.0	2.4	8.1	0.23	1.06	49	-	-	-	Trace
110 - 140	5.0	2	28	17	60	22.2	15.3	2.8	11.9	0.19	1.71	69	-	-	-	Trace
San Francique clay																
0 - 8	5.3	0	4	25	68	25.7	23.1	13.7	8.2	0.91	0.96	90	4.1	0.43	9.5	42
8 - 28	5.0	0	3	20	79	20.7	16.2	9.3	6.5	0.61	0.87	78	1.5	0.21	7.1	20
28 - 50	4.2	0	2	21	82	22.7	13.6	7.4	6.1	0.58	1.84*	60	1.0	0.16	6.3	16
50 - 75	4.7	0	1	12	89	23.6	12.2	5.9	5.1	0.40	3.37*	52	-	-	-	15
75 - 100	4.2	0	1	16	85	24.2	13.1	5.2	5.2	7.7	0.34	54	-	-	-	15
100 - 155	4.2	0	13	22	60	16.1	8.9	3.3	5.9	0.17	5.20*	55	-	-	-	4
Talparo clay																
0 - 5	6.1	4	18	15	65	34.4	36.3	18.7	16.1	2.21	0.88	100	6.2	0.61	10.2	50
5 - 25	5.4	3	8	10	82	29.8	24.0	8.8	13.5	1.64	1.43	81	2.6	0.28	9.3	32
25 - 55	5.0	0	1	4	97	35.4	24.2	5.6	17.4	1.09	2.68	68	-	-	-	21
55 - 100	4.3	0	1	4	96	34.5	23.1	3.1	19.1	0.82	6.27	67	-	-	-	9
100 - 150	4.8	3	2	10	94	33.6	29.7	5.7	26.3	0.65	11.70	88	-	-	-	61

[a] 1:2.5 soil:water suspension [b] pipette method [c] NH_4OAC extraction at pH_7

Table 3. Acidity, cation exchange capacity, exchangeable cations (neutral normal KCl and NH_4Cl extractions) and Al saturation of selected acid Vertisols.

Soil Depth (cm)	pH (water)	pH ($CaCl_2$)	CEC[a]	Ca[a]	Mg[a]	K[b]	Na[b]	Al[a]	Al Sat. (%)
			milli-equivalents/100g soil						
San Francique clay									
0 - 25	4.8	3.6	14.36	5.92	4.11	0.16	0.49	2.50	17.4
25 - 65	5.0	3.8	22.57	3.96	4.66	0.25	1.20	5.79	25.6
65 - 120	5.0	3.5	27.70	4.62	5.48	0.45	2.04	7.22	26.1
La Retraite clay									
0 - 15	6.0	4.9	21.55	8.58	6.99	0.81	0.38	0.60	2.7
15 - 60	4.9	4.0	13.34	5.28	4.66	0.81	0.46	0.97	7.3
60 - 90	4.6	3.6	13.34	3.30	5.21	0.66	1.98	3.36	25.2
90 - 120	4.4	3.6	24.62	3.30	12.06	0.69	1.67	6.02	24.5
Talparo clay									
0 - 15	6.0	4.8	26.62	13.86	8.22	0.66	0.59	0.60	2.3
50 - 75	4.8	3.6	26.62	5.92	8.77	0.61	1.91	4.15	15.6
75 - 120	4.7	3.7	28.98	5.28	13.70	0.66	2.44	4.26	14.7
Bejucal clay									
0 - 25	5.0	3.6	23.60	6.60	3.29	0.61	2.22	6.65	28.2
25 - 75	4.8	3.6	28.73	7.32	5.48	0.46	2.19	9.43	32.9
75 - 120	4.7	3.7	27.70	6.60	4.79	0.56	2.32	7.56	27.3
Debe clay									
0 - 15	4.5	3.7	27.70	14.52	6.85	1.08	1.80	1.76	6.4
15 - 60	4.3	3.6	28.73	10.56	6.71	0.81	1.20	6.02	21.0
60 - 90	4.4	3.7	26.62	9.24	6.85	0.50	3.01	5.11	19.2
90 - 120	4.3	3.7	25.65	9.24	8.22	0.58	3.18	4.49	17.5

[a] based on neutral normal KCl extraction
[b] based on neutral normal NH_4Cl extraction

Table 4. Clay mineralogy of selected acid Vertisols.

Soils	Montmorillonite	Illite	Kaolinite	Others[a]
Buxton clay (Guyana)	15	30	30	25
Talparo clay (Trinidad)	24	20	34	22
Bejucal clay (Trinidad)	20	20	35	25
Debe clay (Trinidad)	18	30	30	22

[a]mainly quartz

the structure of the surface soil is due to other causes. This soil is not inundated but it has appreciable free Fe_2O_3 content (8-10%). On the surface where oxidized conditions exist, the Fe_2O_3 functions in the formation of a fairly good structure. In the subsoil where Fe is mainly in the reduced form, the structural relationships more characteristic of Vertisols are typical.

Soil reaction

From the data presented in Tables 2 and 3 and from similar data available for other acid Vertisols in Trinidad and Guyana, the acidity is often less in the surface cultivated layer and the soil gets increasingly acid with depth. The drop could be almost two pH units. The higher surface values are probably due to the influence of agriculture and the consequent soil amelioration which resulted over time. A good example of this is the Talparo soil which was analyzed in this study; it has a pH of 6.0 in the top 15 cm but this could drop to below 4.0 at depth. The site from which the samples were taken has been cultivated to sugarcane for at least 100 years and had received heavy dressings of ground limestone in the past. At any rate, a survey of 58 sites on Talparo clay in different parts of Trinidad where sugarcane has been cultivated for many years gave an average pH value of 4.7 for the surface soil (Cooper, 1982). The KCl pH is usually about one pH unit lower than the pH of the soil in water, which is similar for other Vertisols (USDA, 1974).

Adjustments of the pH to higher values if considered necessary for agriculture require high dressings of ground limestone--upwards of 10 tons per ha to change pH values from about 4.5 to 5.5 to 6.0.

Cation exchange capacity

In general, the CEC of the acid Vertisols (Table 2 and 3) is not as high as the CEC of other Vertisols in the Caribbean, especially those derived from calcareous and volcanic materials (Ahmad and Jones, 1969), because the clay kaolinite content is much higher in these Vertisols (Table 4). There is also not much difference in the CEC determined at pH7 by NH_4OAC or at the field pH using neutral normal KCl (Tables 2 and 3). The CEC at pH7 is only slightly higher than at field conditions. This is due to the relatively small quantity of montmorillonite which has a high pH independent component. Since these soils are relatively low in organic matter, the contributions to the CEC at the higher pH may not be substantial.

Exchangeable cations

The exchangeable Ca, Mg, K, and Na for all the acid Vertisols reflect some marine influence, at least at the time the initial or secondary deposits were being laid down. For example, ratios and levels of Mg, K, and Ca in particular in relation to state of leaching of the soils at present, would indicate that these cations were much higher and that they have been leached to the present levels. In further support of this, it is to be noted that these cations increase in content with depth of soil. Ca on the other hand

decreases with depth, and this is probably due to the influence of agriculture. The Ca:Mg ratio seems important in acid Vertisols. Mg seems more resistant to leaching in these soils with montmorillonite mineralogy; therefore, with continued exposure to leaching, exchangeable Mg could be even higher than Ca. Exchangeable Na and K increases with depth for most acid Vertisols, again reflecting former marine influence.

Exchangeable Al

Exchangeable Al shows some unusual relationships with soil pH. In Fig. 1, the relationship of Al saturation and pH for several orders is shown. For the acid Vertisols, although the pH could be lower than 4.5, Al saturation is not very high, as is the case with Ultisols and Oxisols especially. Similar data are not easily available for Inceptisols and Alfisols. In Vertisols, unlike the orders with low activity clays, exchangeable H^+ seems to be more important in determining soil pH. It is for this reason that crops are grown on these acid soils without responding to additions of ground limestone or with crops showing symptoms of Al toxicity. Cooper (1982) in a study of the use of lime on some acid Vertisols in Trinidad concluded that Al toxicity begins to influence crop production at pH 4.0 - 4.2. Exchangeable Al does not normally approach even 40% of exchangeable cations when the soil pH approaches 4.0.

There is a great discrepancy in the amount of Al extracted by NH_4OAC at pH7 compared to the amount extracted by neutral normal KCl. This is exemplified by the data presented in Soil Taxonomy (USDA, 1975) for Pedon 125 which is an acid Vertisol. The difference is much greater for acid Vertisols than for other soils at equivalent field pH.

Clay mineralogy

Data on clay mineralogy of the acid Vertisols are limited. The mineralogy of the clays for three Trinidad and one Guyana Vertisol (the Guyana Vertisol is presently classified as Vertic Tropaquepts) is presented in Table 4. Compared to other Vertisols, the acid ones appear to have higher quantities of kaolinite. The vertic properties are, therefore, as much a function of the fineness of texture as it is of the smaller amount of montmorillonite which is present. The kaolinite is largely inherited in the case of the Trinidad Vertisols since the primary source of the deposits which are largely acid Vertisols derived from clay shales, are also rich in this mineral. Due to the low pH, the montmorillonite in these soils are probably weathering to kaolinite; as an indication of this there is evidence of an interstratified kaolinite montmorillonite mineral in some of the clays. The relatively high exchangeable Mg and Al extracted by NH_4OAC may also be an indication of this.

RECOMMENDATION

It is strongly recommended that the suggestion made by Smith (1982) to have acid, nonacid and calcareous families of the various subgroups of

Fig. 1. Relationship between pH and Al saturation for related Ultisols, Oxisols Inceptisols, Alfisols and Vertisols.

(for key to soils see Figure legend).

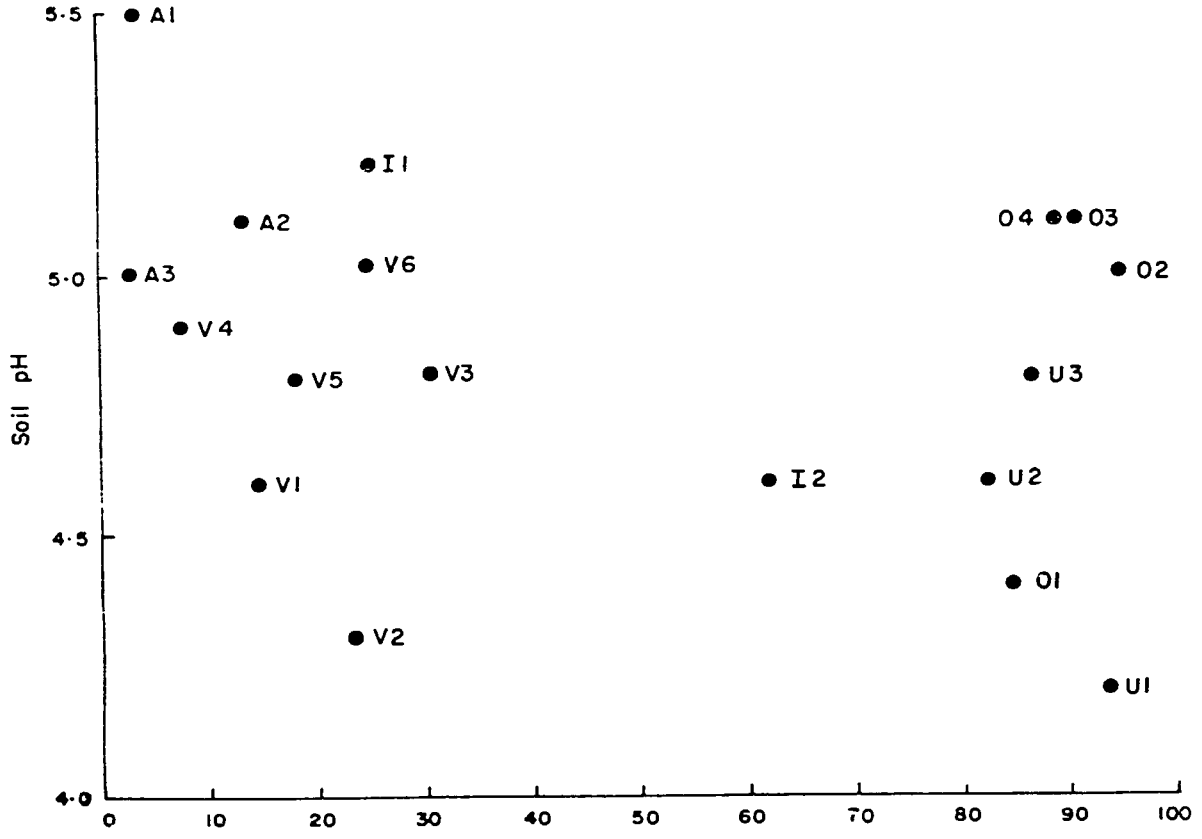

FIGURE 1 - LEGEND

A1 - Pedon 51 - Typic Palendalf (USDA, 1975).

A2 - Pedon 45 - Aeric Glossaqualf (USDA, 1975).

A3 - Pedon 47 - Aeric Tropaqualf (USDA, 1975).

I1 - Pedon 74 - Typic Hydrandept (USDA, 1975).

I2 - Pedon 80 - Typic Dystropept (USDA, 1975).

I3 - Pedon 81 - Typic Eutropept (USDA, 1975).

O1 - Pedon 103 - Haplic Acrorthox (USDA, 1975).

O2 - Pedon 102 - Typic Acrorthox (USDA, 1975).

O3 - Oxisol from Burundi - Typic Acrohumox.

O4 - Pedon 32 - Typic Acrustox (USDA, 1975).

U1 - Pedon 113 - Typic Paleaquult (USDA, 1975).

U2 - Pedon 120 - Typic Tropudult (USDA, 1975).

U3 - Pedon 119 - Typic Rhodult (USDA, 1975).

V1 - Pedon 125 - Entic Pelludert (USDA, 1975).

V2 - Debe clay - Entic Pelludert (Table 1).

V3 - Bejucal clay - Entic Pelludert (Table 1).

V4 - La Retraite clay - Udorthentic Chromusterts (Table 1).

V5 - Talparo clay - Aquentic Chromuderts (Table 1).

V6 - San Francique clay - Entic Pelluderts (Table 1).

Vertisols be given serious consideration. The limits for acid and nonacid members should be pH 5 in water and 4.5 in 0.01M CaCl as proposed. These are realistic values.

In order to establish a comprehensive classification of these wet and low-lying Vertisols where relatively slight drainage differences could be important in development of profile morphology, serious attention should also be given to the suggestion of Comerma and Luque (1982) that a new sub-order be established in which many of these wet soils may be classified.

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VERTISOLS OF VENEZUELA

J.A. Comerma

ABSTRACT

An estimated three million ha of Vertisols occur in Northern Venezuela. Their location in young, flat alluvial plains, occupying back-swamp positions, and their association with better-drained Alfisols in river levee sites, gives these areas a good potential for agriculture. Nevertheless, at present their most extensive use is for rice and pastures due to the drainage conditions.

Most Vertisols come from riverine deposits, a few from lacustrine and marine deposits, and very few from clay-rich rocks. The great majority occur in very flat areas; only the rock-derived Vertisols are in hilly or mountainous conditions. Their climate is primarily Ustic (900-1400 mm/year), in a few areas aridic (< 700 mm), but in all cases with a definitive rainy and dry season. The predominant vegetation is savannah. They are estimated to be of Pleistocene age, equivalent to the Alfisols, as they are almost always associated.

Most Vertisols in Venezuela are more than 1 m deep, with 50% or more clay, high-bulk densities, somewhat poorly to poorly drained, medium to low in organic matter, light colors, blocky structure at the surface, prismatic and with parallelepipeds in depth; very few have gilgai; with low-base saturation at the surface and increasing with depth, carbonates are common only in drier regions; their mineralogy is mixed, vermiculitic, or montmorillonitic but a few are kaolinitic.

The most common pedogenetic processes in sequence are: organic matter accumulation, prismatic structure formation, slickensides, tilting of peds, reduction-ferrolysis, desaturation and mineral transformations.

The main taxonomic problems are: separation of poorly drained from better-drained, desaturated versus saturated, and soil moisture regimes subdivisions.

INTRODUCTION

North of the Orinoco River, which is about half of Venezuela, there are about 3 million ha of Vertisols. Most of them occur in the physiographic region called "Llanos," which is a large, flat depression filled up with alluvial sediments of different origins and ages within the Pleistocene. Vertisols for the most part occupy the position of backswamp deposits in these landscapes. Their association with medium textured, better-drained Alfisols, in the levee position, makes those areas of great value for

agricultural development. Vertisols in these areas are most extensively used for rice and pasture mainly due to the poor drainage situation.

Fig. 1 shows the main area where Vertisols occur in Venezuela; it will be shown later that they occur in varied kinds of landscapes, parent materials and climates, producing a large variation in pedogenesis, characteristics, and classification units.

SOIL-FORMING FACTORS

Landscape settings, parent materials, and time

Most Vertisols in this country are derived from riverine or fluviatile sediments deposited in floodplain and/or deltaic environments. Most of those sediments are either medium or highly base saturated, commonly with free carbonates and sometimes, as in Central Venezuela, with gypsum; micas are also very common in most parent materials.

The two most common geomorphological positions are the so-called "overflow couvette" and the "decantation couvette"; respectively, they are characterized by increasing amounts of clay (about 40 and 60% or more), increasing distances from the river channels, and increasing time of flooding.

A few areas of Vertisols are derived from lacustrine sediments, as in the Northwestern Zulia basin, with similar features to the ones mentioned for the riverine, but with more gypsum and salts. In the east of the same basin, as well as in Northwestern Venezuela, in an estuarine environment, there are some Vertisols derived from marine clays or mixtures of them with riverine; in those, acid sulphate clays or similar soils are formed, and by the amount of fine clay, shrinking and swelling with time develop very acid Vertisols.

Finally, residual Vertisols are found in the eastern hills of Venezuela in slopes of around 5 to 10% derived from marls of Cretaceous age, and in the southern flanks of the Andes in even steeper slopes derived from acid and calcareous argillites.

In relation to time of development, in almost all cases, Vertisols are associated with Alfisols. Their time of evolution is consequently equivalent to the formation of argillic horizons but still having medium or high bases. When we find Inceptisols or Mollisols (like Ustropepts or Haplustolls) in levee deposits, we find in the backswamp-associated deposits Vertic Tropaquepts, which in most cases are considered precursors of Vertisols.

In summary, most of the parent materials are rich in bases and weatherable minerals deposited in quiet waters and with flat surfaces of medium ages affecting the drainage and pedogenesis.

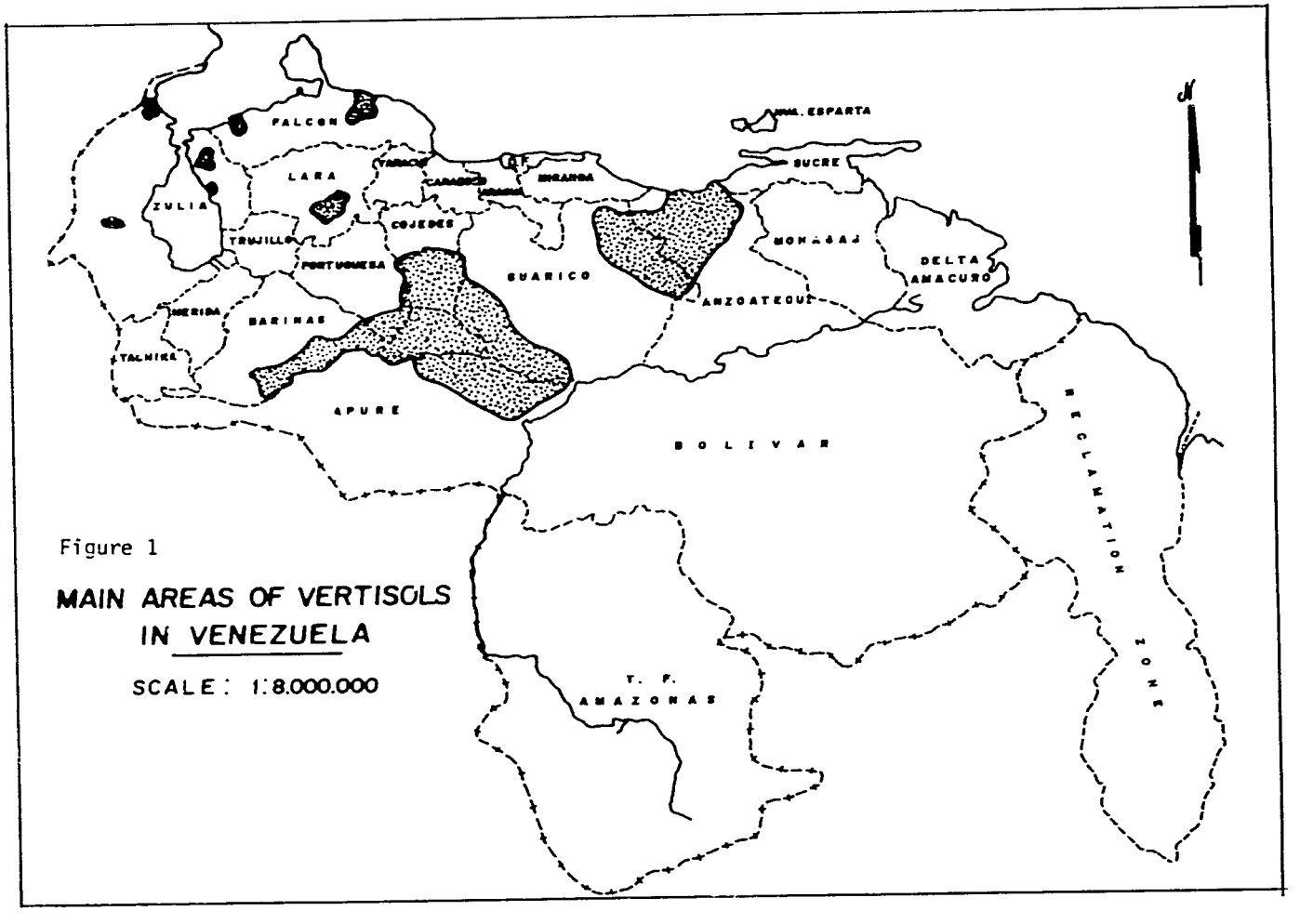

Figure 1

MAIN AREAS OF VERTISOLS IN VENEZUELA

SCALE: 1:8.000.000

Climate and vegetation

The largest areas of Vertisols occur in the so-called "tropical dry forest." This area has precipitations between 900 and 1400 mm with a clear dry season corresponding to ustic moisture regimes. This moisture regime is questionable in many places as, due to the very slow surface drainage, water is ponded on the surface generally over a period of three months every year. This generalized condition, of too much and too little moisture in two periods, produces an absence of trees and a predominance of grasses, many of them adapted to poorly drained conditions. The presumed moisture regime due to the above conditions, the grey colors, and the kind of vegetation is more in the realm of the aquic moisture regime.

The second climatic area in importance is the aridic or torric. In our latitude this corresponds to a precipitation of less than 700 mm per year. The natural vegetation in these cases is mostly of leguminous shrubs like the *prosopis spp.*, and a few cactus. Associated soils in these areas are Hapla, Natra, or Paleargids.

Finally, in the wetter areas considered within the external udic moisture regimes, the amount of Vertisols is very scarce especially in the flat areas.

MAIN SOIL CHARACTERISTICS

Most Vertisols in Venezuela, being of alluvial origin, are generally over 2 m deep, with somewhat irregular clay distribution and in level or concave surfaces. Consequently with these characteristics and with a subhumid monsoonal climate, there are important areas with ponded surface drainage. Most Vertisols in this main climatic region have been classified as poorly or very poorly drained when they have at least three months (cumulative or consecutive) of a water layer on the soil surface. As this occurs during the main period of use of soils in this latitude, it greatly reduces the number and kind of crops or pastures to be used. Only in semi-arid regions or in a few sloping areas where Vertisols occur we are able to find drainage classes qualified as moderately well drained. There is a general relationship between low chroma color soils and reduced drainage conditions and vice versa for Venezuelan Vertisols reported previously (Comerma et al., 1978; Comerma and Luque, 1982). Under these conditions, the predominance of chromas of two or less in the upper 50 cm of the soil separates well the poorly or very poorly from the better-drained ones.

Clay contents of most Vertisols are in the range of 50 to 60%. In areas where the surface drainage produces long periods of ponding, and the materials are noncalcareous or only a little calcareous, there is generally a clay increase with depth on the order of 9 to 13% around the 50 cm depth. In those cases it is common to find low base saturation values, of about 50% by NH_4OAC, increasing in the lower subsoil. Only the Vertisols derived from marine or estuarine clays also have acid pH values. The remaining Vertisols, being the majority, are alkaline generally with free carbonates. In the semi-arid and arid northwestern areas there are some

Vertisols with high amounts of sodium and/or soluble salts.

In relation to organic matter, values are usually on the order of 2 to 3% in the upper 15 or 20 cm, decreasing rapidly with depth. In general, the wetter ones have the higher amounts of organic matter. A summary of the main physical and chemical properties of a selected group of Vertisols is shown in Tables 1, 2, and 3 (Comerma and Luque, 1982). Regarding mineralogy, several Vertisols have shown a wide variety of clay mineralogy, although there is mostly an important component of expansive clays. In Table 3 we can see those results. It seems that the variation in parent materials rather than genetic processes can explain that variation. Concomitant with that mineralogy are the rather low to medium values of the coefficient of linear extensibility (COLE) also observed in Table 3.

Table 3. Content of expansive clays and COLE in 1 m depth.

PROFILE	EXPANSIVE CLAYS (% Soil)	COLE (%) RANGE	$\bar{X}$
La Goajira	11 - 18	8 - 11	9
El Palmar	0 - 6	9 - 13	11
Lagunillas	4 - 5	10 - 12	11
Vaca	4 - 15	6 - 9	8
Valle Hermoso	11 - 29	7 - 14	9
Tucutunemo	$\pm$ > 50	9 - 13	11

In relation to morphological features essential for its grouping with Vertisols, the slickensides are the most constant and prominent features. They generally occur after the upper 30 cm and usually become larger, more tilted and intersecting with depth. It is rather common to find a kind of coarse platy inclined structure on top of the slickensides that breaks into angular blocky parallelepipeds. Irregular A horizons are common, expressing the crack-filling process, but wavy horizons associated with gilgai are very uncommon. Only in semi-arid and arid environments, mostly in lacustrine sediments, do we find good expressions of gilgai. This probably reflects the very high amount of fine clay and/or its montmorillonitic nature.

Table 1. General information on the soil profiles.

Profiles	Bioclimatic Zone	Annual Rainfall (mm)	Landscape	Soil Taxonomy Classification
La Goajira	Thorn tropical woodland	400	Marsh	Typic Pellustert, fine, vermiculitic, isohyperthermic
El Palmar	Dry tropical forest	1,100	Alluvial plain	Entic Chromustert, very fine, mixed, isohyperthermic
Lagunillas	Very dry tropical forest	900	Alluvial plain	Udorthentic Pellustert, very fine, kaolinitic, isohyperthermic
Vaca	Dry tropical forest	1,400	Alluvial plain	Udorthentic Pellustert, very fine, mixed, isohyperthermic
Valle Hermoso	Lower montane, dry forest	1,100	Alluvial plain	Entic (Paleustollic), Pellustert, fine, montmorillonitic, isohyperthermic
Tucutunemo	Dry tropical forest	1,000	Alluvial plain	Typic Chromustert, fine, montmorillonitic, isohyperthermic

Table 2. Main physical and chemical characteristics of selected Venezuelan Vertisols.

Profiles	Clay (%)	Silt (%)	pH H_2O	Org. C. (%)	C.E.C. (me/100g)	Exchangeable cations me/100 g soil				Ele. Cond. (mmhos/cm)	$CaCo_3$ (eq. %)
						Ca	Mg	K	Na		
L.G.	40-44	30-39	6.3-7.5	0.06-0.55	52-62	12-17	7- 8	0.3-0.4	1.1-12.3	0.6-6.0	1.0-4.0
E.P.	55-63	21-27	5.3-7.9	0.30-3.00	35-42	13-25	5- 6	0.3-1.3	1.4- 5.5	0.5-1.5	2.0-4.0
L.	44-85	15-55	4.1-5.3	0.30-2.80	31-40	8-12	13-15	0.2-1.3	1.8-11.7	0.5-5.5	2.3-3.0
V	38-75	24-50	5.1-7.4	0.30-2.20	26-28	17-39	2- 9	0.1-0.5	0.4- 4.3	0.6-2.3	2.0-3.0
V.H.	28-66	33-45	7.6-8.6	0.30-2.10	49-82	11-32	9-14	0.2-0.6	1.6- 9.5	0.5-0.7	5.0-6.5
T.	40-55	42-56	6.5-7.2	0.70-3.20	95-105	21-25	25-32	0.3-0.7	0.1- 0.2	0.3-0.5	non det.

PEDOGENIC PROCESSES

The vast majority of Vertisols in Venezuela are presumed to be derived from Vertic Tropaquepts. These soils are characteristically occupying the backswamp deposits, associated with Ustropepts or Haplustolls in levee positions. Vertic Tropaquepts are clayey, poorly drained, dominated by low chroma grey colors and yellow or brown mottles; with deep cracks, prismatic and blocky structures and some pressure faces; organic matter accumulates, in medium levels, but an irregular distribution of organic matter with depth and roots along the prism faces are common features. Generally, these soils are high in base saturation and in many cases with free carbonates. Water ponding for several months during the rainy season is also common; this drainage situation limits or eliminates the possibility of a forest and favors grasses adapted to lack of oxygen. Maintaining similar characteristics to the ones mentioned above, many Vertisols evolve after several cycles of swelling, shrinking, and some physical mixing. The main evolution features are: an increase in slickensides, the tilting of aggregates, and the formation of wedge-shaped structural units. In areas subjected to ponding and water saturation, it is also common to find an increase in clay with depth, generally on the order of 10-15% and reaching its maximum in the neighborhood of 50 cm depth. In those cases, it is common to find a lower base saturation in the upper half meter with an increase with depth. The low base saturation can reach levels of about 50%, or a pH in H_2O 1:1 of about five or less, while the subsoils can be near 100% with free carbonates. The presumed process could be ferrolysis (Brinkman, 1978) which would account for the lower clay contents in the upper soil, implying clay destruction under these acid conditions and resynthesis in the subsoil. Other processes like clay illuviation, favored by removal of carbonates, cannot be waived. The acidification of the upper soil could also be attributed to ferrolysis.

Soils in which ponding and water saturation are not so pronounced, generally evolve toward Vertisols only by the mixing process and development of slickensides and tilted aggregates, but maintaining a high base status and rather uniform clay distribution down the profile. Nevertheless, it is common to all Vertisols to have some degree of leaching with depth, mostly in the form of carbonates or gypsum accumulation in the subsoil. This suggests that the mixing effect is not enough to overcome a general trend of downward movement and leaching with water.

Mineral transformations have not been sufficiently studied. From the few mineralogical studies (Elizalde and Comerma, 1982), it seems that most clay minerals, from montmorillonitic, vermiculitic, mixed and kaolinitic families, seem inherited from the parent materials. The best chances of transformation would be expected in the ones acidified in the upper soil, but no such studies have been carried out.

The very few areas of Vertisols acid throughout and considered to be derived from marine or estuarine clays, seem to go first through an oxidation of sulfides, acidification, and afterwards, due to a large percent of fine clays with a high component of kaolinites, develop slickensides and tilted structural units, qualifying them for Vertisols.

APPLICATION OF SOIL TAXONOMY

The application of Soil Taxonomy to Venezuelan Vertisols have always confronted some criticism. The most important one has been the deficient separation of poorly and better-drained Vertisols. In a study of this situation (Comerma et al., 1978; Comerma and Luque, 1982) it was found that Pell grouped quite well, poorly and very poorly drained ones, but Chrom grouped only about half of better-drained ones; the other half corresponded to the same drainage classes grouped by Pell. This evidently unsatisfactory grouping was almost completely eliminated if, instead of chromas of less than 1.5 in the upper 30 cm, we used chromas of 2 or less in the upper 50 cm. These characteristics plus the presence of an aquic moisture regime (defined on the basis of ponded water for 3 or more months) have constituted the first proposal (ICOMERT, 1981) for the re-establishment of the suborder Aquert.

Another aspect has been the lack of recognition of acid or desaturated versus nonacid Vertisols. From the reports of G. Smith (1976) from Venezuela as well as from Trinidad, this problem was recognized, and it was proposed to handle it as acid and nonacid families. If a better understanding and definitions are found for these acid Vertisols, probably a higher categorical level than the family for the use of this characteristic may be more useful, especially for countries that do mapping at smaller scales and are forced to use high or intermediate taxonomic levels.

Finally, as in so many other orders, there is a pragmatic need to make a more precise division of climatic regimes. Aridic and udic subgroups of Usterts have been proposed (Smith, 1976) to obtain groupings with a better interpretative power for more specific crops and/or specific agricultural systems.

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THE VERTISOLS OF CHILE

Walter Luzio L.

In the last few years, soil mapping in Chile has been closely associated with soil classsification, particularly from the moment that Soil Taxonomy (Soil Survey Staff, 1975) was recognized as the official system of soil classification for Chile. Consequently, we have at present suitable soil information on restricted areas where detailed soil surveys have been made through government or private agencies. In addition, diverse genetic studies have provided a large amount of analytical data and also a useful interpretation of soil processes and classification.

Chile occupies the southwest part of South America from 18° to 56° South Latitude in the continental part. With the available information, it is possible to obtain a broad subdivision of the country according to soil moisture regimes (Fig. 1). From 18° to 32° S. we have the aridic (extreme) moisture regime; from 32° to 38°, the xeric moisture regime; and from 38° to 41° the regimes are udic and perudic. The areas with Vertisols are located in the xeric moisture regime. However, they could also occur in zones that have not been surveyed.

In the region with xeric soil moisture regime, the Vertisols are usually located in the low sites of basins which are often poorly drained. The hydraulic conductivity of the soils is low to very low. In the northern part of the xeric moisture regime area (dry xeric) (Van Vambeke and Luzio, 1982), there exists a number of Vertisols with high levels of salinity and, in some cases, with high levels of sodicity, considering the figures of exchangeable sodium percentage.

MATERIALS AND METHODS

Soil survey reports and scientific papers were reviewed with the purpose of studying the main characteristics of the Vertisols of Chile.

RESULTS AND DISCUSSION

Geology and soils of the central part of Chile

In the central part of the country, between 32° and 41° S. there are three well-defined physiographic units: the Andean Mountains, the Central

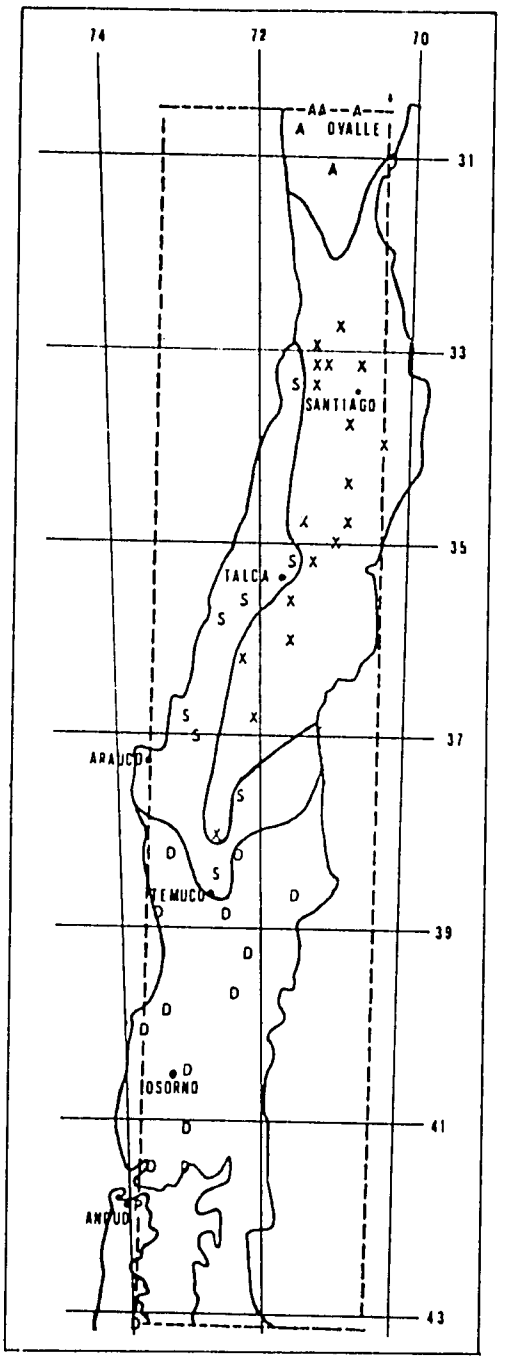

Figure 1. Soil moisture regimes between the Elqui Valley and the Chiloe Island. A: Aridic; X: Xeric, S: Ustic; D: Udic; P: Perudic.

Valley and the Coastal Range or Cordillera, going from east to west. During the middle Cretaceous, the deep marine sediments were folded, resulting in the main features of the relief. After that during the Terciary period, and as a consequence of tectonism, the three physiographic units differentiated into two mountain ranges, of north-south direction, and a Central Valley, which is considered a graben from a geological point of view.

In the western part of the Andean Mountains there are volcanic rocks, mainly of the andesitic type, with inclusions of continental sedimentary rocks and some lacustrine deposits from the Upper Cretaceous (Fuenzalida, 1958). Glacier and water erosion have produced deep and narrow valleys with steep slopes. Over 1700 m altitude, in areas with slopes of around 25%, the soils are shallow and gravelly with only an ochric epipedon as a diagnostic horizon. In the highest altitude there are Cryorthents and in the lowest altitude, near the Central Valley, Xerorthents. Also, some Histosols occur in the inter-mountain valleys.

Towards the west, the Andean Mountains enter abruptly into the Central Valley, which is a tectonic depression. The crystalline metamorphic base is covered with deep layers of sediments that may reach a thickness of 500 m. They are of volcanic, alluvial and glacial origins, but, at present, it is thought that the principal way of deposition is in the form of volcanic mud-flows, widely known as lahars (Marangunic et al., 1979). The result of this situation is that the surface of the Central Valley has been permanently rejuvenated. Thus, the stability degree of the surfaces is very low and consequently the argillic horizons are not frequent, although some Xeralfs in the northern part and some Xerults in the southern part of the Central Valley have been described. Ochrepts, Orthents, Xerolls, and some Xeralfs are the most representative soils of the area.

The altitude of the Coastal Cordillera is lower than that of the Andean Mountains and occasionally exceeds 1000 m. This range is a granodioritic batholith which is the principal parent material of reddish soils (5YR), with high clay content and very well-developed argillic horizons. Xeralfs to the northern part of this physiographic unit, and Xerults to the south are the most important soils. As a consequence of water erosion, there are gently undulating areas.

Important features of the Vertisols of Chile

In order to simplify the discussion, the two Great Groups that are described for the Central part of Chile: Pelloxererts and Chromoxererts (Chile, 1977; Chile, 1981) will be individually referred to.

Pelloxererts

Exchangeable complex. The CEC does not show any clear tendency with depth; in some profiles there is only an increase in the subsoil and then a decrease again in the deepest horizons. The figures go from 14.5 meq/100 g in a horizon from Quella soil series (Chromic) (Table 1) to 86 meq/100 g in a horizon from Quiahue soil series (Typic) (Table 1). The exchangeable complex is dominated by bivalent cations, Ca^{++} being the most important. Normally, the calcium saturation exceeds 50%.

Table 1. Properties of some Pelloxererts (Typic Xeric).

Soil Series	Sub Group	Prof (cm)	O.M. (%)	pH	CEC (meq/100g)	E.C. (mmho/cm)	ESP (%)	$CaCO_3$ (%)
Alantaña	Entic	0-16	3.8	6.4	35.4			
		16-48	2.2	6.6	44.7			
		48-76	2.2	6.2	45.3			
		76-110	2.4	6.4	53.7			
Almahue	Entic	0-16	5.4	7.4	46.2			
		16-40	2.3	7.6	45.2			
		40-120	1.2	7.6	43.2			
Polonia	Typic	0-15	5.9	5.8	46.4			
		15-56	2.2	6.7	46.7			
		56-90	1.9	7.2	61.6			
		90-100	1.6	7.2	60.8			
		110-150	1.6	7.3	55.6			
Quiahue	Typic	0-16	5.5	7.0	72.0			
		16-37	2.4	7.4	86.0			nodules
		37-90	1.9	7.2	75.9			nodules
		90+	0.3	7.9	61.9			petrocalcic horizon
Quella(1)	Chromic	0-8	1.7	5.9	19.0			
		8-36	0.8	6.8	23.4			
		36-45	0.7	6.8	24.0			
		45-60	0.7	6.6	23.6			
		60-68	0.5	6.6	24.5			
		68-105	0.1	7.0	14.5			
Quella(2)	Chromic	0-6	2.0	5.7	33.5			
		6-20	1.4	5.6	35.6			
		20-50	0.8	5.9	36.1			
		50-60	0.3	6.1	36.3			
		60-75	0.3	7.1	30.6			
		75-100	0.3	7.3	22.9			
Sta. Clara	Typic	0-13	5.5	6.0	21.0			
		13-25	1.6	6.0	20.3			
		25-53	0.8	6.8	26.8			
		53-85	0.4	7.5	25.9			

Organic matter. The organic matter decreases gradually with depth in all the profiles, which is a very normal situation. It is necessary to note, however, that Pelloxererts have a high organic matter content in the surface horizons if we compare the figures with the other soils of the Central Valley. Occasionally, the organic matter content in the epipedons of the Ochrepts, Orthents, Xerolls, and Xeralfs is higher than 3%. In the Pelloxererts 5% or higher are frequent figures.

Salinity and sodicity. There is a clear difference in pH between the Pelloxererts from the Typic Xeric area and those from the Dry Xeric area. The ranges in pH for the first case go from moderately acid (5.6) to moderately alkaline (7.9), but in the second case they range from mildly alkaline (7.5) to strongly alkaline (8.8) (Table 2).

In the Dry Xeric area, some Pelloxererts show high electrical conductivity throughout the profile (6.5 - 14.5 - 9.9 - 6.1 mmho/cm). Besides, some soils show high calcium carbonate content (about 9%) (Table 2). Some of the last ones are developed over a petrocalcic horizon, whose upper limit varies from 50 to 90 cm depth.

One of the soils that was classified into the Typic subgroup showed a very high exchangeable sodium percentage[1], with depth: 19 - 54 - 67 and 78% (Table 2). Actually, it is an alkaline soil which has been described as having a dispersed structure.

All these soils with calcium carbonate accumulation and high exchangeable sodium percentage are located in a basin of about 22,000 hectares, which has hindered drainage.

Chromoxererts

Exchangeable complex. As in the Pelloxererts, the figures for CEC have a wide range from 14 meq/100 g to 74.4 meq/100 g (Tables 3 and 4). It is also possible to observe a light tendency to increase at the level of the subsurface horizons in some profiles. Therefore, no difference in CEC was detected among both subgroups. In the same way, the exchangeable complex is saturated with the same bivalent cations, i.e. Ca and Mg, with the exception of three profiles that were classified into the Palexerollic subgroup showing high exchangeable sodium percentage. The highest value described in the Batuco Soil Series was 85%, between 51 and 63 cm depth (Table 3).

Organic matter. The decrease of organic matter content with depth is the only clearly detected tendency in the profiles. Like in the Pelloxererts, the organic matter content of the epipedons is higher than that of the Ochrepts, Xerolls, and Xeralfs from the same region.

Salinity and sodicity. Again, it is possible to show clear differences among the soils located in the Typic Xeric areas and the soils of the Dry Xeric areas.

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[1]The exchangeable sodium percentage was considered as a measure of the sodicity in the reports reviewed. Data on sodium adsorption ratio (SAR) are scarce.

Table 2. Properties of some Pelloxererts (Dry Xeric).

Soil Series	Sub Group	Prof (cm)	O.M. (%)	pH	CEC (meq/100g)	E.C. (mmho/cm)	ESP (%)	$CaCO_3$ (%)
Chincolante	Chromic	0-10	6.7	7.8	49.2	2.3	6	1.2
		10-51	6.0	7.9	50.6	1.1	5	2.3
		51-100	0.9	8.2	27.2	2.3	9	40.6
La Vilana	Typic	0-6	4.1	7.8	38.8	6.5	19	2.4
		6-57	1.7	8.2	46.3	14.6	54	2.8
		57-80	1.2	8.6	44.8	9.9	67	6.6
		80-120	1.2	8.8	40.6	6.1	78	8.7
Urraca	Typic	0-26	4.5	7.8	35.7	2.5		4.1
		26-60	3.4	7.5	68.6	2.9		0.2
		60-82	2.9	7.7	63.0	2.7		3.1
		82-85+	1.7	8.0	51.1	1.0		7.3

Table 3. Properties of some Chromoxererts (Dry Xeric).

Soil Series	Sub Group	Prof (cm)	O.M. (%)	pH	CEC (meq/100g)	E.C. (mmho/cm)	ESP (%)	$CaCO_3$ (%)
Chicureo	Palexerollic	0-25	1.9	7.4	23.7	0.4		0.0
		25-70	1.6	7.8	33.8	0.5		0.0
		70-86	1.4	7.9	50.1	0.8		0.8
		86-102	1.0	8.1	47.8	1.0		1.1
		102-120	0.3	8.4	45.6	0.8		2.3
Peralillo	Palexerollic	0-8	7.9	7.6	55.1	23.0	11	0.0
		8-36	4.5	7.4	51.1	15.8	20	0.0
		36-90	1.7	7.6	46.4	8.8	23	0.0
		90-120	0.5	7.5	40.0	6.3	19	0.4
Rungue	Palexerollic	0-15	4.5	7.0	40.7	0.4		0.1
		15-43	2.1	7.7	48.2	0.3		0.1
		43-66	1.2	8.0	50.3	0.4		0.1
		66-98	0.9	8.2	47.1	0.4		0.7
		98-120	0.5	8.1	43.2	0.6		2.9
Totoral	Palexerollic	0-5	4.0	7.7	20.4	8.5	23	8.7
		5-18	3.3	8.1	39.9	10.8	7	3.0
		18-50	1.6	8.5	47.0	8.7	68	2.0
		50-80	1.2	8.8	46.7	7.1	100	1.6
Batuco	Palexerollic	0-5	4.8	7.9	34.4	3.1	16	2.4
		5-24	1.2	8.5	38.2	2.5	36	3.0
		24-51	0.3	9.2	46.1	4.2	84	6.3
		51-63	0.3	9.3	40.3	8.7	85	17.4
		63-90	0.3	8.9	33.2	18.0	83	4.9
		90-120	0.2	9.2	24.8	6.0	60	7.7

Table 4. Properties of some Chromoxererts (Typic Xeric).

Soil Series	Sub Group	Prof (cm)	O.M. (%)	pH	CEC (meq/100g)	E.C. (mmho/cm)	ESP (%)	$CaCO_3$ (%)
Colchagua	Typic	0-19	4.9	6.3	41.6			
		19-73	1.0	6.4	39.7			
		73-106	0.5	7.9	47.0			
		106-125	0.6	8.2	57.8			nodules
Huique	Typic	0-20	2.4	6.5	40.6			
		20-79	1.2	7.4	52.4			nodules
		79-105	0.3	8.0	64.2			nodules
		105-115	0.2	8.0	61.8			
		115+	0.2	8.0	62.6			
Lihueimo	Typic	0-15	4.4	6.8	35.0			
		15-46	1.1	7.1	39.4			
		46-87	0.7	7.5	43.4			
		87+	0.0	7.1	14.2			
Los Cardos	Typic	0-26	1.9	6.8	41.5			
		26-64	1.1	6.7	38.0			
		64-98	0.8	7.0	38.5			
		98+	0.2	7.0	32.4			
Pupilla	Typic	0-15	2.5	6.2	28.0			
		15-55	0.6	7.4	36.0			
		55-90	0.3	7.8	74.4			nodules
		90+	0.1	7.8	51.8			

The average value of the pH for all the soils from the Typic Xeric is 7.2, and the extreme values are 5.8 and 7.9. In some profiles, calcium carbonate nodules were described but they are not considered as concentrations of significance (Table 4).

The average value of the pH for the soils of the Dry Xeric sector is 8.1 and the range is 7.4 to 9.2. Some of these soils may reach a calcium carbonate content of about of 17%. Three soil series of the Dry Xeric area classified into the Palexerollic subgroup show high exchangeable sodium percentages and they are considered as saline-alkaline soils (Table 3).

CONCLUSIONS

There have been in Chile some difficulties in classifying the Vertisols of the Dry Xeric moisture regime, particularly those soils that show salinity and sodicity. We consider that both of these conditions are of the greatest importance for land use and soil management. Consequently, considering that these properties have not been considered in Soil Taxonomy, we suggest the definitions of a saline and/or alkaline subgroup at least for Xererts.

SUMMARY

In order to characterize the Vertisols of Chile, soil survey reports and a number of scientific papers were reviewed.

Exchangeable complex, organic matter content, and salinity and sodicity were the soil properties taken into account. Only Pelloxererts and Chromoxererts are described for the central part of Chile. No differences were detected among them in exchangeable complex and organic matter content.

On the contrary, salinity and sodicity appear closely associated mostly with soil moisture regimes. Thus, several Pelloxererts and Chromoxererts from the Dry Xeric area, bordering the aridic, show high electrical conductivity and high exchangeable sodium percentages. Neither Pelloxererts nor Chromoxererts show salinity and sodicity in the Typic Xeric moisture regime area.

A definition of a saline and/or alkaline subgroup, at least for Xererts, is suggested, considering the importance of both properties for land use and soil management.

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VERTISOLS OF AUSTRALIA

J.W. McGarity

ABSTRACT

Soils that qualify as Vertisols are widespread in Australia and include members of the black earth, wiesenboden, grey, brown and red clays, prairie, rendzina, humic gley and chocolate soils Australian great soil groups. The cracking clays (Ug) of "A Factual Key" most nearly approximate the Vertisol order.

The properties that are used as differentiae at high categorical level in these classifications are morphological and, apart from texture, include color, soil structure, presence or absence of carbonates, pH reaction trend, and depth. Horizon arrangement of Vertisols is difficult to describe as genetic designations are inconsistent. New terms appear to be needed to describe horizons. Chemical and physical characteristics that are related to differences between soils include ESP, clay mineralogy, and plant-available water.

The use of the enlarged pedon concept for gilgai microrelief tends to conceal the diversity in physical, chemical, and biological properties that are important in management. Areas where Soil Taxonomy needs further examination for Australian conditions are discussed.

INTRODUCTION

Vertisols are widespread in Australia; the total area of these and related soils has been variously estimated at 108 million hectares (Dudal, 1965) and 48 million hectares (Hubble, 1981). The discrepancy in the calculated area arises from uncertainty as to which great soil groups qualify as Vertisols. The wide range of properties of soils with vertisolic characteristics reflects variation in parent materials and the different climatic and geomorphic factors of many regions in which they occur (Fig. 1).

In this paper, the properties of Australian Vertisols which have major significance in classification and management are outlined.

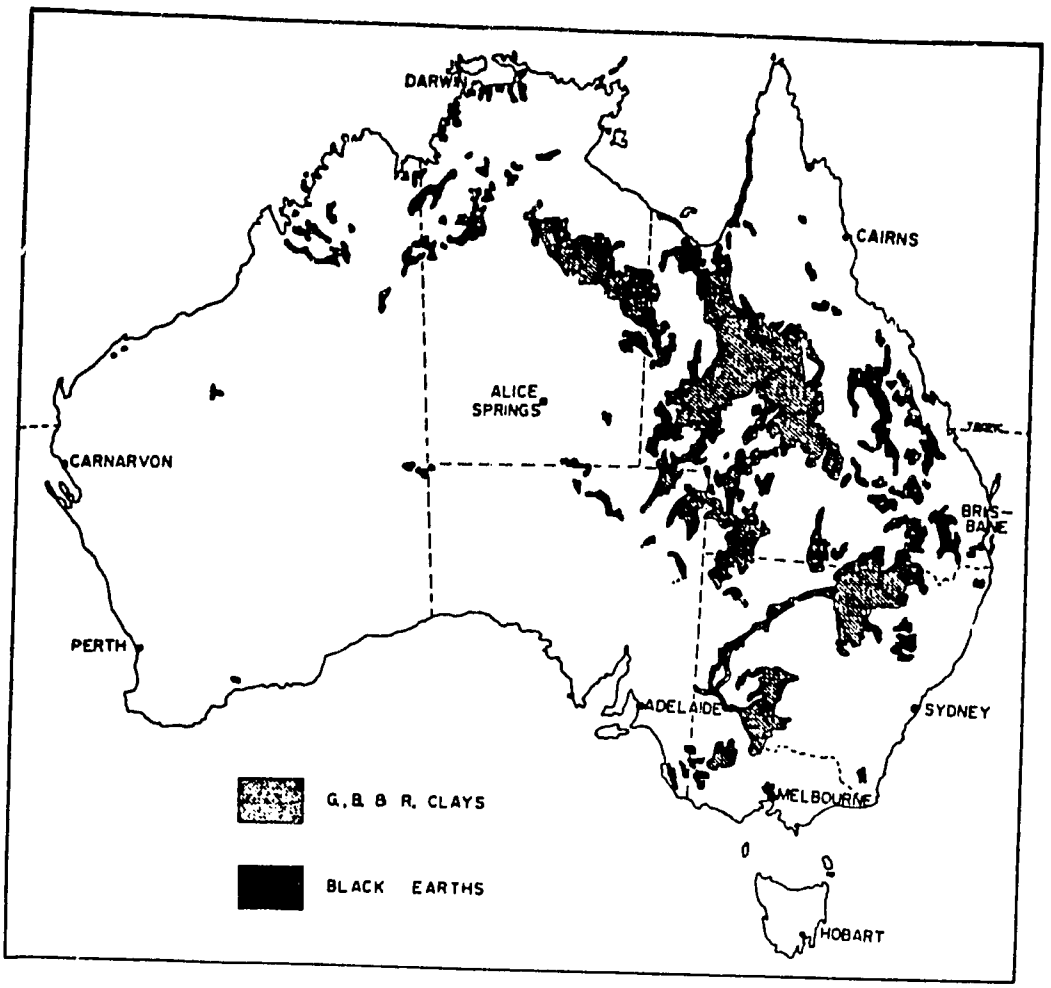


Figure 1. Major areas of Vertisols. (Adapted from "A Soil Map of Australia" in Stace et al., 1968.)

THE CLASSIFICATION OF AUSTRALIAN VERTISOLS

The term "Vertisol" as a grouping for cracking clays is not currently in common use in Australia because Soil Taxonomy has yet to gain general acceptance. Two schemes--the national Australian Great Soil Group Classification (Stace et al., 1968) and A Factual Key (Northcote, 1971)--require and report only some of the differentiating criteria that are needed to classify soils within Soil Taxonomy (Soil Survey Staff, 1975). Both classifications rely heavily on morphological properties observed and measured in the field, and little or no direct weight is given to quantitative characteristics determined in the laboratory. (See Butler, 1980.)

The great soil groups that are considered to qualify as Vertisols are listed in Table 1. Descriptive names derived from A Factual Key are included. The most relevant characteristics of those great soil groups that qualify as Vertisols and vertisolic intergrades are abbreviated from the group desc iptions in "A Handbook of Australian Soils" (Stace et al., 1968).

Black earths

Weakly differentiated, shallow to deep uniform dark alkaline clays (50-80% clay), with closely spaced wide, deep cracks and a self-mulching surface. Consistence is hard, dry, and very plastic and sticky, wet. Structure is the main differentiating feature in the upper solum, and increases in coarseness with depth, passing into increasing slickensides and related structures associated with slip faces.

Grey, brown, and red clays

Weakly horizonated, deep cracking soils of uniform high clay content (50-80%), uniform color which fades with depth and may be alkaline or acid throughout or alkaline over acid at depth. Apart from color and texture, structure differentiation is the most striking feature, varying from self-mulching to platy and massive surface horizons to lenticular and slickensided subsoils. The range of properties is too wide for one group. Properties other than color seem more important as differentiae.

Wiesenboden

Dark, uniform-textured clays with mottling and concretionary iron. These are mostly hydromorphic black earths but include noncalcareous members that are more closely related to prairie soils.

Rendzinas

Fine-textured members are virtually indistinguishable from shallow black earths.

Table 1. Vertisolic Great Soil Groups with Factual Key and FAO equivalents.

Great Soil Group	NORTHCOTE KEY		World Soil Map
	Descriptive name[a]	Factual Designation	
Black earths	Black self-mulching cracking clays	Ug 5.12,.13,.14,.15, .16	Pellic vertisol
	Black structured earths with smooth ped	Gn 3.43, .46	Luvic phaeozem
Grey, brown, and red clays	Grey, brown, and red self-mulching clays	Ug 5.22,.23,.24,.25, .26,.27 Ug 5.32,.33,.34,.35, .37,.38,.39 Ug 5.5	Chromic vertisol
Rendzinas	Black self-mulching clays	Ug 5.11	Pellic vertisol
Wiesenboden	Black self-mulching and massive clays	Ug 5.16, Ug 5.4	Pellic vertisol
No suitable group	Black and grey massive clays, underlain by buried soils	Ug 5.17, Ug 5.4 Ug 5.5	Pellic vertisol Chromic vertisol
Chocolate	Non-cracking friable clay with smooth ped fabric	Uf 6.32 (Ug 6.1)	Phaeozems
Prairie	Non-cracking friable clays and loams with smooth peds	Uf 6.1 Um 6.3 (Ug 5.1)	Kastanozems Phaeozems
Humic gley	Non-cracking dense pedal and plastic clays	Uf 6.4 Uf 6.6 (Ug 5.2)	Humic gleysol

[a]Compiled from Northcote et al., 1975.

Chocolate soils

Weakly differentiated, medium to shallow dark friable clay soils. Slickensides may be present. (Stace et al., 1968, is non-specific regarding surface cracking which occurs in some members with expanding clays.)

Prairie

Includes uniform moderate to deep dark, light clays grading into yellow-brown to red blocky or prismatic subsoils. The non-calcareous uniform textured soils grade towards black earths and are better regarded as non-calcareous members of the group. (Slickensides are not referred to in the description.)

Humic gley

Includes high organic matter containing acid clays developed on stratified alluvium with gleyed subsoil. Subsurface structure may be strong coarse prismatic, with parallelepiped structural units and showing gilgai.

Uniformity of texture, and cracking and structural features are the important characteristics common to these descriptions, with color differences, the presence or absence of carbonates, pH trend, and mottling associated with drainage, the most important criteria for drawing a distinction between the groups.

A Factual Key uses different criteria and in this scheme the Ug soils, the cracking clays of Northcote et al., (1975), fall loosely into the order of Vertisols. These are "soils with uniform fine-textured profiles that crack open periodically upon drying." Uniform fine-textured is defined as greater than 35% clay throughout the solum. "The intention is to include all clay soils with gilgai microrelief and others which crack but show doubtful, if any, gilgai formation. It is specifically intended to exclude those soils which have only a self-mulching or crumbly surface soil and do not crack open during the dry season." (Northcote, 1971)

This definition allows inclusion of shallow cracking clays (> 30 cm) and clays of humid areas where moisture deficits are not experienced. The definition might exclude some soils that have gilgai microrelief but lack open cracks (see Knight, 1980).

The major properties used in the key in the system of bifurcation from the primary profile form to principal profile form are listed (Table 2). Emphasis is placed on structure, including fabric, as the criterion to differentiate to the subsection level. Color and depth are the criteria used at the lower class level.

THE PROPERTIES OF CRACKING CLAYS

The comparative abundance of data in surveys describing the morphology of the Australian equivalents of Vertisols is unmatched by quantitative data on chemical, mineralogical, and physical characteristics. Many diagnostic properties, e.g. COLE, are lacking in these reports, which hampers their use for classifying these soils according to Soil Taxonomy.

Table 2. Schematic differentiation of Ug 5 cracking clays.

Texture	- Uniform fine clay textural class	- U (Primary profile form)
Structure	- Cracking seasonal or periodical	- Ug (Subdivision)
Organization		
	[- Sporadic bleached A2 - Ug 3]	
	- Predominantly smooth-faced peds	- Ug 5 (Section)
	[- Predominantly rough-faced peds - Ug 6]	
Structure All		
	- Self-mulching, granular, blocky	- Ug 5a (Subsection)
	- Massive or coarse	- Ug 5b
Color:horizon below All		
	- Dark; grey; brown	- Ug 5.1:5.2:5.3 (Class)
Color, depth to D, D, buried soil: subsoil-subsolum		(Principle profile form)
	- Dark	- Ug 5.11 thru 5.17
	- Grey	- Ug 5.21 thru 5.25
	- Yellow-grey	- Ug 5.26 thru 5.29
	- Brown	- Ug 5.31 thru 5.35
	- Red	- Ug 5.36 thru 5.39
Color:horizon below All		
	- Dark; grey; brown	- Ug 5.4:5.5:5.6 (Class)

Soil morphology

Color. Uniform low value, low chroma colors, becoming gradually paler with depth, characterize many Australian Vertisols (Hubble, 1981). Dark colors (values < 3, chroma < 3, VC1) are typical of soils developed on basic rocks or derived alluvium. The colors of the subsurface horizon, which is generally 30-120 cm thick and underlies the A11, is regarded as definitive in A Factual Key (Northcote, 1971). The color groupings of the subsurface horizons are: dark (VC1), grey and yellow-grey (VC2, 3, hue > 10 YR), and brown and red (VC4, 5, for brown, hue > 7.5 YR). The dark clays (VC1) include both pellic and chromic great groups of Soil Taxonomy. The A11 (1-5 cm) may have the same colors as the underlying horizon or paler colors due to silt and sand accumulation.

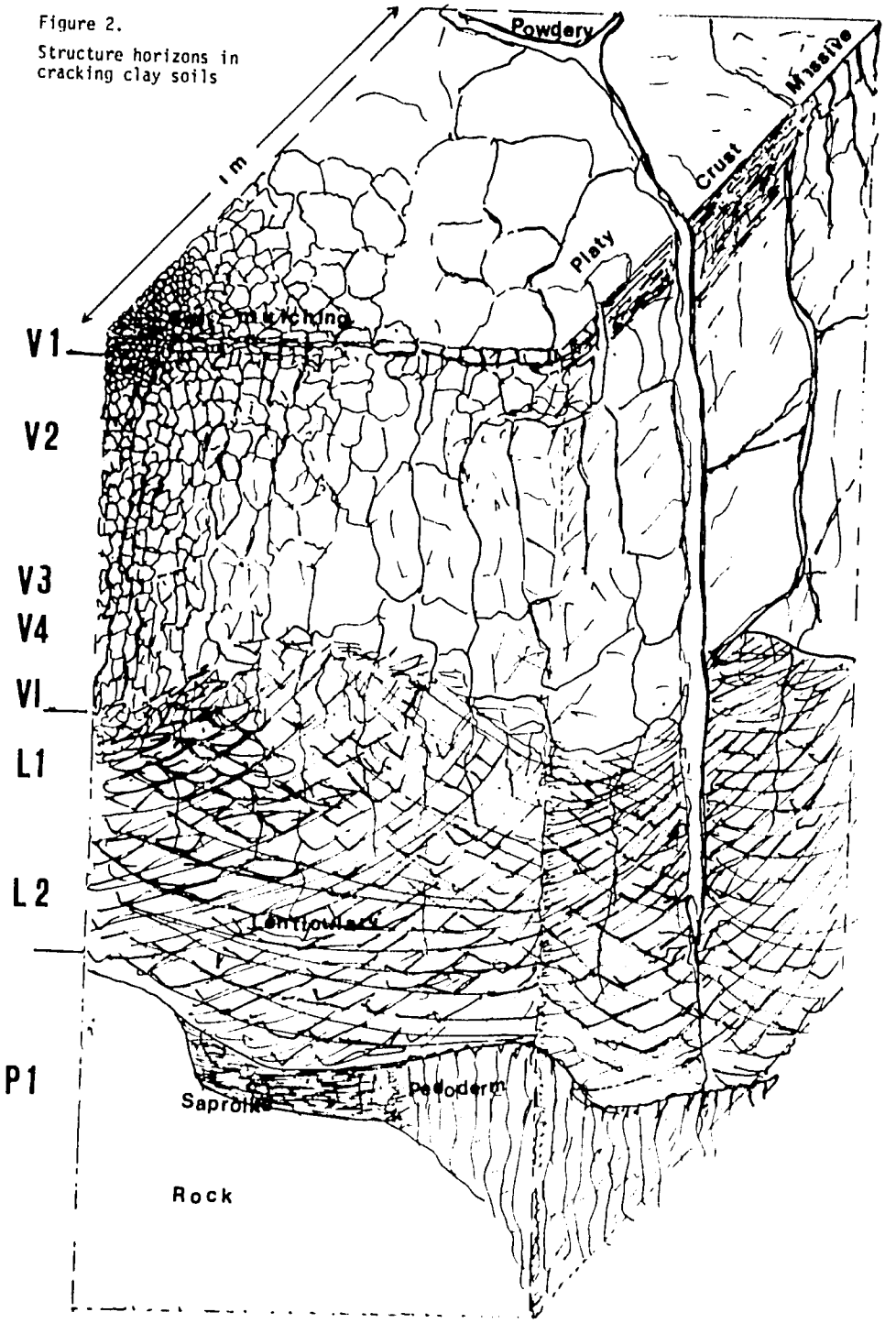
The darkest colors occur in sedentary soils, grey on poorly drained alluvium, brown on better-drained, higher alluvial terraces, and red on redistributed alluvial soil materials from relict surfaces (see Northcote et al., 1960-68). This generalization fails where red and brown clays occupy floodplain or interdune depression lines and where grey clays are found on old surfaces (Lorimer, 1981). A further complication occurs where brown subsoil and subsolum are carried to the surface by gilgai processes. Color may not provide a satisfactory basis for predicting the nature of soil processes, or utilization.

Depth. Many cracking clays occur on flat or gently undulating alluvial or colluvial landforms. Expansion and contraction of subsoils increase downslope movement and consequently on upper and mid-slope positions on basaltic and fine sedimentary rocks, the solum is of moderate depth (50-85 cm) compared with those on foot-slopes. Shallow black earths in Queensland (such as the Purrawunda Series; Thompson and Beckmann, 1959) may have a lithic contact at less than 50 cm but otherwise have similar properties to contiguous soil bodies with lithic contact at 80 cm included within the series. Linear gilgai appears to develop only where there is a minimum depth of about 80-100 cm of expansive clay. A depth of 150 cm is a differentiating criterion although, under small grain cropping in the semi-arid zone, moisture depletion rarely exceeds 120 cm. This distinction of deep and not-so-deep sola is complicated where the deep unconsolidated fine-textured alluvium of Holocene and Pleistocene age shows discontinuities within the depth of the solum. On the northwest plains of New South Wales, a mottled, noncracking "pedoderm" exists at approximately 80-120 cm over part of the landscape. This layer exhibits mottling, mangans, angular block structure, little stratification, few slickensides, and a lower frequency of cracks than in the horizons above. Sleeman and Brewer (1981) reported that 9 out of 27 profiles described in Stace et al., (1968) and elsewhere had one or more discontinuities and buried surfaces. These discontinuities can be detected in thin sections, even in gilgaied complexes, although not apparent from field descriptions. The distribution of carbonates, which sometimes changes at depositional breaks, is considered to be pedogenetic (Sleeman and Brewer, 1981).

Depositional breaks which are inherent in these soils create difficulties using A Factual Key and in applying conventional genetic horizon designations. Acid and excessively calcareous subsola merge into upper sola and have important management implications.

Figure 2.

Structure horizons in cracking clay soils



Structure. Although the cracking clays are described as weakly differentiated (Stace et al., 1968), structure is a salient characteristic that shows consistent patterns with depth. Self-mulching surfaces and lenticular subsoil structure are cited as unique properties (Hubble, 1972). Self-mulching and massive structure are used as high-level differentiae in A Factual Key and in the 7th Approximation (U.S.D.A., 1960).

At least four groupings of structural horizons can be discerned in many Australian cracking clays (Fig. 2):

1. The surface horizon (A11, Northcote, 1971) varies from a loose, thin (1-2 cm) self-mulching or crusty plate (5 cm) to a massive or blocky structure.

2. The horizon below the A11 has wide, deep cracks between which medium to coarse rough-surfaced subangular blocky peds with poor accommodation are most frequently developed. Below this again, at 20-30 cm, there is a gradual change to angular blocky which may be coarser, making up weak but cohesive semi-columnar units. Some units lying between the wide cracks may be massive. Nonintersecting slickensides may be present, changing gradually into the horizon below.

3. Peds bounded by intersecting slickensides often with wedge or lenticular shape.

4. A nonslickensided, massive or structured horizon having saprolitic, depositional or buried soil fabric.

The loose, self-mulching peds of the A11 vary from strong fine to medium granular or subangular blocky and may form weak plates of extreme fragility. Where dispersion occurs due to ESP > 5, polygonal plates of varying thickness are formed from peds "welded" at points of contact. Increasing thickness and cohesiveness is an extension of this dispersibility, leading to development of hard duplex crusts. Massive and calcareous and saline powdery surfaces may also develop.

The biological activity of the cracking clays is largely governed by the physical characteristics of the second group of horizons. The structures and cracking patterns, a consequence of shrink-swell phenomena and management (McGarry, 1981), determine air and water entry, ability of roots to extend and the depth of subsoil incorporation of loose organic residues and surface soil. Rate of water entry swings between extremes as cracks, pores, and fissures close on wetting (Loveday, 1972). Even at high moisture contents, differing permeabilities are possible, depending on the extent of fissured and vughy materials (Sleeman and Brewer, 1981).

Increasing massiveness from about 20-45 cm may reflect high ESP. Variation in structure development in the gilgai complex may cause the pedon to behave as two entirely different soils, each of which would be recognized as distinct bodies if geographically separated. Cracking clays containing amorphous lime and high organic matter usually have finer, more stable peds but consistence is usually hard when dry, and sticky when wet. This differs from the concept of a "soft" mollic epipedon although diagnostic requirements of color, and organic matter and P content may be met.

The two horizons described have similarities to the *verton* proposed by FitzPatrick (1980). Together, the upper horizons comprise an epipedon which is uniquely characteristic of Vertisols possessing definable swelling and cracking properties, structure development, high clay content, and biolog activity.

The third horizon comprises peds with smooth faces due to shearing caused by movement. Lenticular or parallelepiped structures are usually present, particularly where gilgai are developed. Thickness is variable and mottling frequent. According to Beckmann et al., (1981), this horizon has plastic limits that are lower than in the overlying horizons and consequently are subject to flow at similar moisture contents. The lenticular units slake readily and lack interped cohesion and may be squeezed as mukkara into gilgai mounds. The horizon frequently exhibits different colors, including coatings, organic matter and mineralogy, from overlying materials. Large surface cracks extend into this horizon.

Lithic or paralithic contacts may underlie the slickensided horizon. Under the clay plains in northwestern New South Wales the pedoderm lying between 80 - 140 cm shows features of previous biotic activity which strongly contrasts with the overlying slickensided horizon. Few surface-connected cracks penetrate this horizon which may be calcareous or noncalcareous and have interlocking subangular blocky peds with mangans. It may mark the effective depth of moisture removal or a change to noncracking clay.

Carbonate and gypsum. Hard or soft concretions occur in all soils except in neutral and acidic groups (prairie, humic gleys). Hard concretions are generally found on the surface of gilgaied soils or below 30 cm, mixed with soft concretions in soils with and without gilgai. Powdery carbonate may occur on the mounds of gilgai complexes, giving a "puffy" surface which sometimes contrasts with crusty surfaces on contiguous sodic-influenced depressions. Incorporation of lime mitigates adverse structure (Loveday, 1972) and continued mixing of subsurface horizons by cultivation can eventually ameliorate such soils. Rendzina-like cracking soils with abundant amorphous carbonates may develop from deep-weathered basalt in which carbonate has accumulated (Gunn, 1974).

Gypsum is usually present in the solum when summer rainfall is less than 650 mm or winter rainfall less than 400 mm, but is influenced also by parent material and topographic position (see McDonald et al., 1981). It generally occurs at 60 - 75 cm and underlies the horizon of maximum carbonate accumulation.

pH-reaction trend. In a climatic transect across northern New South Wales, cracking clays show a progressive increase in surface and subsoil pH from 1200 mm annual average precipitation (Casino) where surface pH values of 5.5 are common to 550 mm annual average precipitation (Moree) with surface pH of 7.7. Soils under higher rainfall may have acid clay in contact with carbonate nodules in deep subsoils (e.g., Pelican clay, Nicholls and Tucker, 1956) in contrast to those with accumulations of carbonates within the upper 30 cm in less leaching environments. Soils with acid reaction lacking carbonates occur in littoral depositional landscapes in the Northern Territory (White, 1981). Acid subsoils underlying alkaline horizons are common in grey and brown clays (Reeve et al., 1963). The climatic pH trend is masked by effects of upward movement of acid or alkaline subsoil in gilgai, of age and position on landscape and of parent material.

Management problems are significant and diverse as, for example, where acid subsoils in gilgai extend into the crop root zone (Fig. 3). Many Australian pedologists believe that pH trends (and carbonate status) should be included in any classification at a high categorical level as it has major significance in Australian cracking clays. Northcote (1981) favors four classes of differentiae as used in A Factual Key, while Hubble (1981) has proposed alkaline, strongly alkaline, alkaline over acid, and acid divisions.

Chemical and physical characteristics

The chemical data for black earths and grey, brown and red clays described in "A Handbook of Australian Soils" have been summarized by Williams and Colwell (1977) (Table 3). Other data are considered below.

Clay mineralogy. In general, montmorillonite is the dominant clay mineral in the black earths derived directly from basic rocks. Where mixing of colluvium and alluvium from different sources has occurred, contents of other minerals increase and montmorillonite may be absent (Norrish and Pickering, 1977).

In central Queensland shallow soils derived from basalt have very well-developed crystalline montmorillonite with only trace kaolinite. Alluvial derived clay soils have less well-developed crystalline montmorillonite; kaolinite increases in the older soils and those with acid subsoils (McDonald et al., 1981). In the same region, grey clays derived from Tertiary clays have montmorillonite and kaolin codominant with some illite. Illite is more prevalent in the Pelluderts of southern Australia (Hubble, 1981). In the Northern Territory, kaolin clays are relatively dominant in the younger vertisols of the littoral plain (Stewart, 1956; White, 1981).

Cation status. In general, Ex Ca exceeds Ex Mg (Williams and Colwell, 1977). Younger littoral soils and humic gleys have higher Mg (White, 1981; Nicholls and Tucker, 1956). Ex K appears to be lower in older soils (McDonald et al., 1981). Calcium dominates in the grey brown and red clays of the clay plains where contents of $CaCO_3$ and $CaSO_4$ are high. Ex Na is generally low in basalt-derived soils but is sufficiently high (ESP > 5) in alluvia and mudstone-derived clays to affect surface and subsurface structural stability. ESP in the range of 5-14 is regarded as sodic and is associated with crusty and massive structure in the upper profile but it may be mitigated if soft, powdery lime is present. The Ex Ca:Mg:Na ratios are structure-related properties that have relevance to classification. The natric horizon of Soil Taxonomy does not adequately characterize these properties.

Salinity. Some cracking clays developed over basalt accumulate salts when watersheds are cleared in S.E. Queensland but only in semi-arid regions are salt levels significant at root depth.

Plant-available water capacity (PAWC). The cracking clays have the capacity to store considerable quantities of water for plant use. Water is taken up from depths of 80-150 cm under dryland crops and the available store lies close to 100 mm for the grey and brown clays and 200 mm for black earths. However, the conventional estimation, using 1/3 and 15 bar moisture tension, does not reflect the capacity in the field for cracking clays to take up or relinquish water. Using indirect methods, McDonald et al. (1981) found little difference between soils derived from basalt and alluvium, confirming results

(Stirk, 1963). Experience from irrigated soils suggests that surface cracking is not necessarily a good crite-ion for estimating water balance or availability of water.

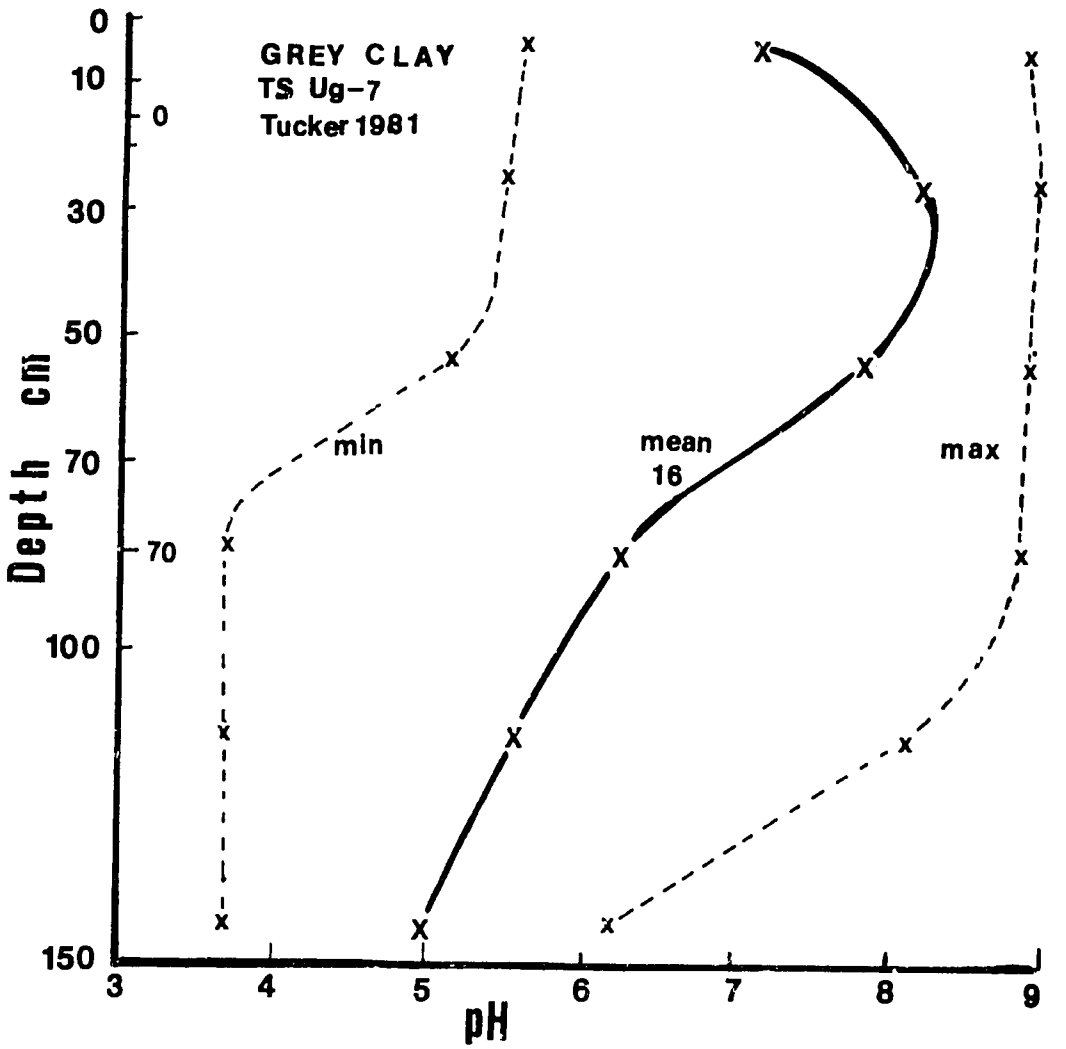


Figure 3. pH variation in alkaline/acid grey clay. (After Tucker, 1981.)

Table 3. Chemical characteristics of vertisolic great soil groups.

Property	Black earth[a]		Grey, brown, red clay	
	Surface range	Subsurface trend	Surface range	Subsurface trend
pH	6.0- 8.0	increasing	5.8- 9.0	increasing
Sol. salt. %	0.5- 1.0	increasing	0- 0.45	increasing
Free $CaCO_3$	0.0- 3.2	increasing	0- 1.5	increasing
Organic matter %	5.5-18.0	decreasing	0.2- 7.0	decreasing
Na me/100g	0.4- 1.1	increasing	0.2- 1.8	increasing
K me/100g	1.5- 2.7	decreasing	0.4- 3.6	decreasing
Ca me/100g	15.0-40.0	decreasing	5.0-38.0	increasing
Mg me/100g	11.0-15.0	increasing	5.0-20.0	increasing
$NaHCO_3$-p (ppm)	10.0-25.0	decreasing	2.0-200.0	decreasing
Total S%	0.7- 0.7	steady	0.01-0.18	steady

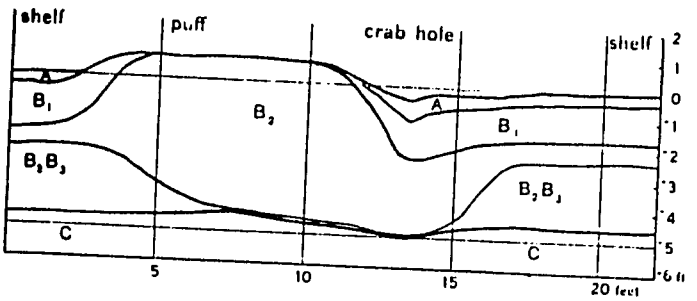
Source: Profiles described in Stace et al. (1968), modified from Williams and Colwell (1977).

[a]Black earth - 3 profiles; grey, brown and red clay. - 12 profiles.

GENETIC CONSIDERATIONS

Horizon designation

Published descriptions of pedons show that the standard genetic designations (A, AC, C, A(B)C) are inconsistently applied to the horizons of Vertisols despite guidelines proposed by FAO (Dudal, 1965). This is not surprising as the mass transfer of surface material (A11) to depth and movement of deep subsoil (C) to the surface differs entirely from the concepts inherent in the original nomenclature. The problem of designation is compounded in gilgaied soils where lateral continuity is disrupted as shown many years ago (Fig. 4; Prescott, 1931).



A—Eluvial horizon = loamy clay.
B_1—Illuvial horizon = heavy clay.
B_2—Illuvial horizon = heavy clay with nodular calcium carbonate.
B_3B_3—Illuvial horizon = heavy clay with calcium carbonate and gypsum.
C—Parent material = Riverina alluvium.

Figure 4. Section across gilgai formation near Griffith, N.S.W. (Prescott, 1931.)

In Australia, structural B (Hubble, quoted by McDonald et al., 1981) and color B horizons are described but definitions are lacking. Terms expressing both the attributes and origin of the material comprising horizons would improve definition (see FitzPatrick, 1980). There appears to be a need to define a vertic epipedon and to provide a new letter designation (see Fig. 2).

The gilgai pedon

The gilgai processes create lateral variability in soil material distribution which is described poorly by the surface manifestation of microrelief. Soil Taxonomy and other classifications, by implication, use gilgai as an identifying characteristic of the Vertisol order. Not all gilgai microrelief is associated with Vertisols (Knight, 1980; Ollier, 1966). Neither is all subsurface displacement manifest in surface microrelief (Paton, 1974), nor is the genesis of all gilgai the same (Beckmann et al., 1981).

The half-cycle enlarged pedon concept applied to gilgai does not describe the complexity of the system where three or four sections of the gilgai complex could have individual standing (suborder to series) in classification schemes. Some pedologists believe that this variability should be recognized and pedons described within the complex as the characteristics of these "subpedons" have vastly different effects on the activity of both natural and agricultural biota.

CONCLUSIONS

In summary, properties which influence Australian classification and management and which seem to have inadequate status in Soil Taxonomy and soil structure, depth of profile, reaction trend and sodic and calcareous diagnostic horizons. The unique character of Vertisols is derived from a genesis that mixes and displaces horizons and so defies the consistent use of the conventional designations. The separation of "epi-" and "hypo-" pedons, based on structural attributes, may provide a more logical means of describing the horizon sequences. The lateral variability induced by gilgai processes and interaction with "*in situ*" processes leads to development of genetically-related individuals (subpedons) which are biologically dissimilar within the gilgai complex.

Australian pedologists[1] believe duration of cracking is not a good criterion for defining moisture regime, that additional color classes may be justified, that surface structure should have categorical status and that the presence of gilgai should not be a criterion for the order. They are not generally agreed on the categorical level at which these criteria might be applied.

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[1]Mimeo: Comments by G. Beckmann, Workshop on Soil Taxonomy, C.S.I.R.O. Brisbane, November 1981.

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THE VERTISOLS OF THAILAND

Pisoot Vijarnsorn

ABSTRACT

Due to the unique regional environment under a Tropical Savannah climate, the Thai Vertisols occupy only about 336,500 hectares throughout the country. They are developed from transported materials mostly originating from limestone, marl, basalt, and andesite. A dark color, wide and deep cracks in the dry season, and a high smectite content are the most common properties of the Thai Vertisols. They contain a high content of organic carbon in the surface horizon, high CEC, high available potassium but low available phosphorus. Soil pH ranges from 5.5 to 8.0, normally becomes more basic with depth.

Only four great groups of Vertisols, namely Chromuderts, Pelluderts, Chromusterts, and Pellusterts have been recognized in Thailand. However, some problems in the classification of these soils using Soil Taxonomy have been encountered and some proposals for changes are discussed and included in the text.

Thai Vertisols have been exclusively used for intensive cultivation of paddy (wetland) rice and some upland crops, namely maize, cotton, mung bean, banana, and fruit trees. Nevertheless, problems in their uses have been encountered due to the unfavorable conditions from soils that are either too wet or too dry to cultivate, waterlogged for long periods of time or suffer the risk of a water shortage during the dry spells.

INTRODUCTION

Due to the unique morphological characteristics and high shrink/swell potential of Vertisols, these soils have become the epicenter of pedological and edaphological interest for the soil scientists. These soils have been called the "Black Earth" soils by the Thai farmers and were first mapped as the Lopburi Clay and Chaibadan Clay by Pendleton and Montrakun in 1960. Later on, these soils were grouped and placed in the great soil group "Grumusols" when the soil classification system outlined by Dudal and Moormann (1964) was used as a basis for classification by the Soil Survey Division. In recent years most of these soils have been considered to be in the order Vertisols, according to the USDA Soil Taxonomy system which at present has been applied in lieu of the old classification system in Thailand.

The Thai Vertisols, although occurring to a small extent throughout the country, are one of the most important soils that have been used exclusively for crop production. At the same time, not much work has been done in Thailand to understand all aspects of their behavior, characteristics and potential land uses. Nevertheless, during the previous field mappings and soil samplings for routine analysis, particularly during the detailed reconnaissance surveys, there has been enough data available for their recognition. Therefore, this paper attempts to highlight the distribution, characteristics, classification, and utilization of the Vertisols occurring in Thailand.

REGIONAL CHARACTERISTICS

Vertisols mostly occur in the central plains, central highlands and, to a lesser extent, in the northeastern plateau, extending from 14° 30' to 17° 00' N latitude and 100° 00' to 105° 00' E longitude (see Fig. 1). They cover an area of about 336,500 hectares which constitutes roughly 0.65% of the total geographical area of the country. Such a small areal distribution of these soils is due to a unique regional environment resulting from the combination of soil-forming factors as follows:

Climate

The climate governing the formation of the Thai Vertisols is essentially a monsoon climate type or the so-called Tropical Savannah (Koppen "Aw"). The overall climate in the Vertisols region experiences a pronouncced dry season with mean annual rainfall ranging from 1,089 to 1,592 mm. The rainy season usually begins in May and ends in October. The temperature in this region shows slight variation within the seasons. In general, April is the hottest month (28° C - 32° C) and the coldest month (23° C - 25° C) is December.

According to the field observations, it is apparent that the monsoon-type climate with alternative dry and wet periods is favorable to the formation of the Thai Vertisols. Therefore, these soils have never been found to occur in the areas having high and well-distributed rainfall such as the southeastern coast and peninsular Thailand.

Parent material

The Thai Vertisols mostly originate from soil materials containing a dominance of smectite in the clay fraction. Most commonly, these materials are associated with marl and limestone-derived alluvium and to a lesser extent, from basalt and andesite. In the central plain where Thai Vertisols mostly occur, marl and limestone play an important role in the formation of Vertisols. If there is marl underneath, the soil depth may be variable from moderately deep to very deep.

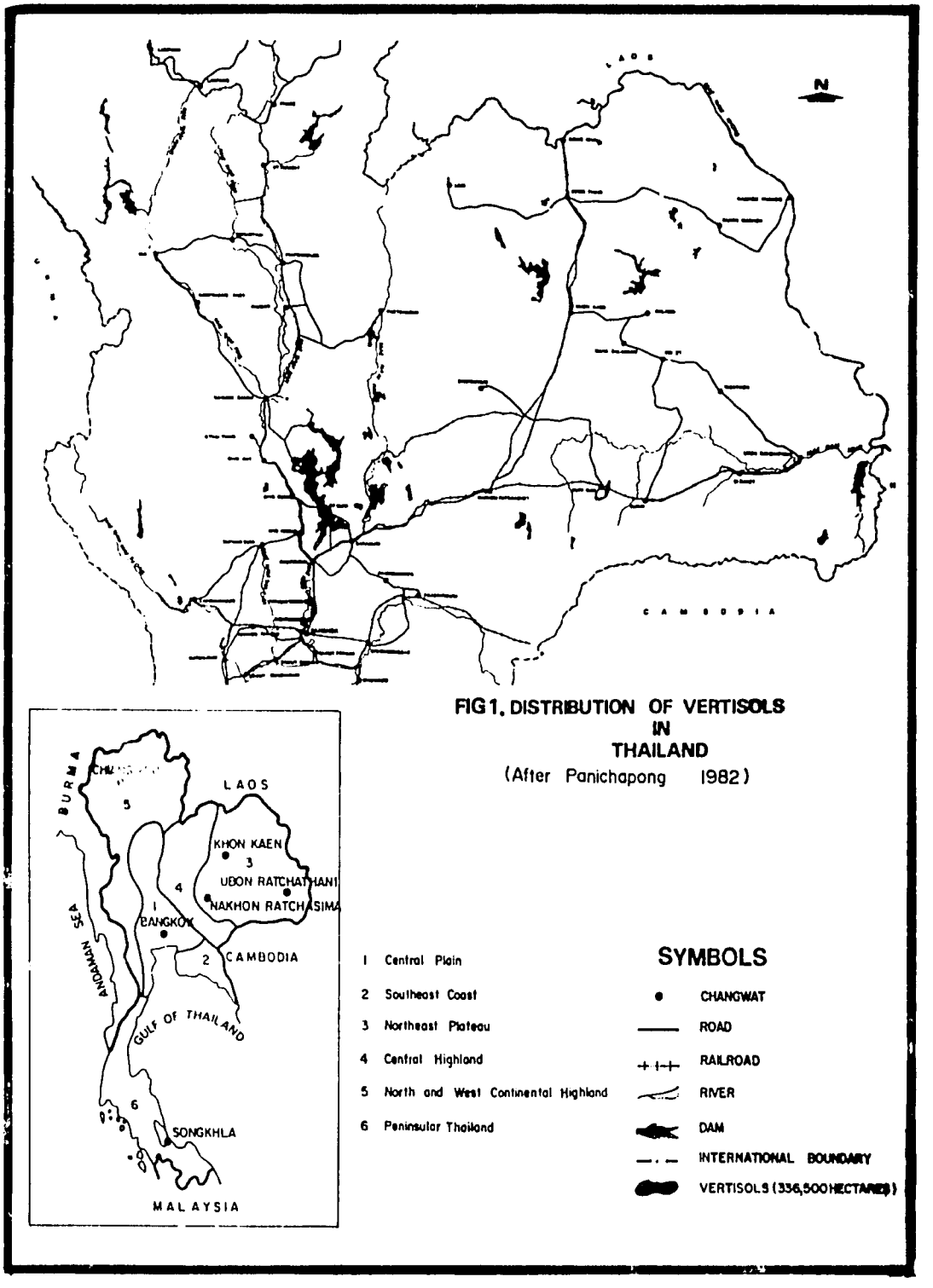

FIG 1. DISTRIBUTION OF VERTISOLS IN THAILAND
(After Panichapong 1982)

Relief and topography

Vertisols in the central plain occur at altitudes ranging from 5 to 25 m above msl, whereas 60-100 m and 150-180 m is normal in the central highlands and in the northeastern region respectively. In general, these soils are found on various micro-landform units including both depositional and erosional. For the depositional facies, particularly in the central plain, most of them occur on flat or nearly flat topography and in depressed areas adjacent to the deltaic plains in the northeastern margin. They also are confined in some valley floors, intervening basins or the flood-plains of river systems in other regions. For the Vertisols developed on erosional features, especially in tropical Karst topography and pediments, the soilscape becomes more pronouncced (undulating).

Vegetation

Most of the Vertisols in Thailand have been utilized for crop production. The normal crop husbandry on the flat lands consists mainly of paddy rice, which can produce two crops a year if the land is irrigated. On the dry land, the most common crops being grown include cotton, maize, and ground nuts. Fruit trees like banana, papaya, mango, and custard apple are also commonly grown on these soils.

MAJOR SOIL CHARACTERISTICS

Morphology

Morphology is the most attractive characteristic used for identifying the Thai Vertisols in the field. Once the soil surveyor observes soils having a dark color, wide and deep cracks, and very heavy clay, they would classify the soil as a Vertisol. In addition, these soils exhibit a high degree of uniformity throughout the profile. Thus only A horizons and C horizons are characterized. However, in many cases, particularly for the paddy soils, presence of brownish and reddish mottles in the subsoil may cause problems in horizon identification.

As shown in Table 1, most of the Thai Vertisols have chromas ranging from 1 to 2 in 10 YR hues. Mottles, if occurring, are generally found in the soils used for growing paddy rice; the quantity of these mottles commonly decreases with depth. Soil structure of the surface horizons in general are weak to moderate, fine to medium subangular blocky or granular, while in the subsoil, the structure becomes less dominant and converts to massive. The most common properties found to occur in most parts of the subsoil are slickensides or pressure faces and wedge-shaped aggregates.

Due to plowing or puddling of these soils for rice cultivation, gilgai relief or microrelief on the surface is seldom observed. However, in abandoned lands gilgai reliefs are found to be common but are relatively small (30-60 cm wide by 30 cm deep). In dry conditions, these soils crack deeply but these cracks will close when the soils become wet, either due to rain water or irrigation water.

Table 1. Range in characteristics of Thai Vertisols.

Horizon	Moist color	Texture	Structure	Slickenside	Width of crackin (cm)	Mottles	Other features	Land Use
			Chromuderts					
Ap	10 YR 4-3/1	C	1 f to m sbk or gr	-	2-8	common fine brownish mottles	-	Paddy rice (flooded about 4-5 months/year)
C	7.5 YR-10 YR 4-5/2 (1)	C	1-2 m to c sbk-bk or massive	distinct	1-2	few to common brownish and reddish mottles		
			Pelluderts					
Ap	10 YR 2-3/1	C	1-2f to m sbk-gr	-	2-10	common to many fine brownish or yellowish mottles	manganese, iron/manganese and lime concretions are common below 80 cm	Paddy rice (flooded about 5-6 months/year)
C	10 YR 2-4/1-(2)	C	1 m-c sbk-bk or massive	distinct	1-3	common to many fine brownish and yellowish mottles		
			Chromusterts					
Ap or A_1	10 YR 2-3/2	C, SiC, CL	1-2 f sbk-gr	-	1-5	-	lime concretions increase in quantity with depth	Upland crops, tree crops and Dipterocarps
C	2.5 Y, 10 YR, 7.5 YR 3-1/2-6	C	1 m-c sbk-bk	distinct	1-2	-		
			Pellusterts					
Ap	10YR 2-3/1-2	C, CL, SiCL, SiC	1-2 m-c sbk-gr	-	2-10	common fine to medium brownish mottles present if used for growing paddy rice	iron concretion and lime concretion are common in subsoil	Paddy rice, upland crops and tree crops (if being used for paddy rice, soil has been flooded for 4-5 months/yr)
C	10 YR 2-4/1(2)	C	1-2 m-c bk to massive	distinct	1-2	-		

Physical and chemical properties

Texture. The texture of Thai Vertisols is usually fine and can range from clay loam, silty clay loam, silty clay or clay in the surface and clay in subsoil. The clay content in the surface varies from 34% to 84%, whereas in the subsoil, the clay ranges from 44% to 96%. The silt fraction is moderately high but the sand fraction is rather low. Gravels mostly occur in the forms of lime concretion, iron and manganese concretion, and weathered fragments of parent materials.

Organic carbon. Most of the soil surface horizons normally contain organic carbon ranging from 1% to 3% but it may go as high as 4.8% in a typical profile of a Pellustert. The distribution of organic carbon, in general, decreases with depth. It may be as low as 0.2% in the deepest subsoil. It has been reported that Vertisols in tropical regions, especially in Africa and India, were remarkably low in organic carbon due to extended cultivation (Finch and Venkateswarlu, 1982) and most of the organic matter was strongly tied to the clay lattice forming clay-organic complexes (Blokhuis, 1982). The Thai Vertisols are rather different. Even if parts of this organic matter were to be incorporated in clay fractions, some of the highly decomposable organic matter can be accumulated in significant amounts under alternate submergency and drainage conditions when the Thai Vertisols are being cultivated with paddy rice. This may be the reason why Thai Vertisols are rather high in organic matter content, particularly in the surface soil.

Soil reaction. Soil reaction of the Thai Vertisols is variable depending largely upon the nature of the parent material and physiographic situations. However, most of them tend to become more alkaline with depth, having pH value ranging from 5.5 to 8.0. At places, particularly for some Vertisols (Chromusterts) in the central plains, acid pH's ranging from 5.0-5.6 have also been observed.

Cation exchange capacity. The cation exchange capacity (CEC) of Thai Vertisols is normally high, ranging from 23 to 82 meq/100 g soil. The high value of the CEC in these soils can be attributed to the high clay content and the presence of the smectite group of clay minerals as indicated by their mineralogy and particle size class distribution. The noteworthy aspect is that the most dominant cations are comprised of calcium and magnesium.

Available phosphorus and potassium. Available phosphorus (P-Bray II) of the Thai Vertisols, in general, is relatively low, varying from 3-12 ppm, but it may be as high as 30 ppm in some Pellusterts. The poor availability of phosphorus in the soils is caused by the presence of calcium or calcareous materials. Therefore, phosphorus is considered to be one of the most limiting nutrients in the Thai Vertisols. On the contrary, most of the Thai Vertisols are found to be rather high in available potassium, ranging from 49 to 247 ppm.

Clay mineralogy. According to the analytical data, the dominant clay minerals in most Thai Vertisols belong to the montmorillonitic group. However, vermiculite, illite, and kaolinite were also observed. It is interesting to note that soils in the great group Chromuderts which are found to develop on alluvium in the central plains have "mixed" mineralogy. This may suggest that these soils might be also classified in the "vertic" subgroup of Tropaquepts.

Table 2. Major physical and chemical properties of Thai Vertisols.

Horizon	Particle size distribution			Organic Carbon (%)	CEC (me/100 g soil)	Sum bases (me/100 g soil)	pH (1:1 H_2O)	P Bray 2 (ppm)	K (NH_4 OAc) (ppm)	Mineralogy of the clay fraction (2-0.2μ)
	sand	silt	clay							
						Chromuderts				
Ap	6-23	25-43	50-67	0.7-1.6	23-40	31-36	5.0-5.3	2.6-4.4	56-159	Mixed vermiculite mont-morillonite, illite and kaolinite
C	3-17	18-28	60-79	0.4-0.6	27-41	36-44	5.0-5.6	1.9-3.4	79- 99	
						Pelluderts				
Ap	2-13	12-50	39-84	1.1-2.7	29-53	20-45	5.1-5.8	2.5-13.6	56-188	Mainly montmorillonite with some kaolinite vermiculite and illite
C	1-12	2-46	51-96	0.2-0.5	34-53	31-50	5.8-8.0	1-10	49-122	
						Chromusterts				
A_1 or Ap	9-26	38-47	39-70	1.1-3.1	31-52	29-40	5.4-7.2	3-12	154-263	Mainly montmorillonite with some kaolinite and illite
C	3-18	10-28	53-85	0.2-0.8	35-65	22-60	5.5-8.0	2- 8	81-213	
						Pellusterts				
Ap	2-33	11-46	34-84	1.2-4.8	22-82	31-82	5.5-8.1	3-30	80-247	Mainly montmorillonite with some kaolinite
C	2-26	11-44	44-87	0.4-2.6	30-82	30-7[illegible]	6.0-8.4	3-31	54-150	

SOIL CLASSIFICATION

According to Pendleton and Montrakun (1960), the dark gray or black clays in Thailand were called either Lopburi clay or Chaibadan clay, which later on were placed into Grumusols (Dudal and Moormann, 1964). However, as more data became available and the USDA Soil Taxonomy system was adopted, most of those soils were classified as Vertisols. At present, these soils are placed into the subgroups Aquentic Chromuderts, Entic Pelluderts, Typic Pelluderts and Udic Pellusterts. However, the Pellusterts and Pelluderts appear to occur quite extensively.

Problems concerning the classification

There have been some problems in the application of the USDA Soil Taxonomy system for classification of the dark gray or black soils of Thailand into the order Vertisols, particularly problems concerned with the field identification of these soils. These problems can be summarized as follows:

1. *Uderts or Usterts?* When these soils are used for growing dry-land crops or are found to occur on undulating terrain, most of them could be placed into Usterts without serious problems. But when they occur on lowlands and are being used for growing paddy rice (wetland rice), there can be classification problems. The great proportion of Thai Vertisols are found on a flat to slightly depressed topography which is ideal for wetland rice. With bunding, together with receiving water from rainfall, from overflows, or from irrigation, these soils will usually be flooded in the rainy season, at least for three months a year. In this case, periods of cracking are relatively variable depending upon soil moisture, the water regime, and climate. The same kind of soils at the same place may be classified into Usterts, Uderts, or the udic subgroup of Usterts (cracks remain open 90-150 cumulative days). Even more soils once classified as Usterts can be changed to Uderts if irrigated for most of the year for the purpose of growing a second rice crop. According to Soil Taxonomy (1975), one of the attributes desired is: "The differentiae should keep an undistributed soil and its cultivated or otherwise man-modified equivalents in the same taxon insofar as possible."

Thus, by using the period of cracking as well as width and depth of cracking as a single differentiation (especially in the suborder and subgroup level) is not quite appropriate because: (1) this property can be easily changed by ordinary cultivation management, and (2) cracking can be observed in the field if the period of investigation is suitable, i.e. the soil is dry enough.

2. *Chromuderts or Pelluderts? Chromusterts or Pellusterts?* The criterion being used to distinguish "Chromu" from "Pellu" great groups is that the "Chromu" must have a chroma, moist of 1.5 or more dominant in the matrix of some subhorizon in the upper 30 cm in more than half of each pedon. In addition, the great group "Chromu" seems to be better drained and occurs on higher topography.

According to our observations and data collected on 36 profiles of Vertisols that occur on the low-lying topography (slope less than 1%) which is normally flooded in the rainy season and exclusively used for growing wetland rice or paddy rice, it appears the color of the soil matrix in the upper 30 cm of subhorizons have the chromas ranging from 1 to 2 of 10 YR hue. Thus, when one measures the soil color, the color of 10 YR 2/1, 2/2, 3/1, 3/2, or even 4/1 and 4/2 can be included in the normal error of measurement. So what is "Chromu" or "Pellu"?

However, it should be noted that the Vertisols occurring on undulating terrain, which have been named the "Wang Chomphu" series, appear to fit very well in the great group Chromusterts because they have the chromas ranging from 3 to 6.

3. *Vertic subgroups or Vertisols?* To distinguish the clayey soils of Vertic subgroups from the Vertisols. Vertisols must have gilgai, slickensides close enough to intersect, and wedge-shaped peds. However, for the soils that are mainly on the back swamps of floodplains or on the depressions and contain a high clay content, cracking and slickensides are commonly observed. Gilgi relief is never developed, or if developed, can be destroyed by puddling. It is not a problem for identification of the slickensides or wedge-shaped peds but of the cracks themselves. The depth and width of cracks can be variable depending upon moisture conditions. Therefore, it is not practical to use cracking as an essential property to separate Vertic subgroups from Vertisols.

Proposal for modification of the classification

In order to classify the problems as previously discussed, we would like a modification for the Vertisols as follows:

1. Although cracking is the common property for Vertisols, we feel that the duration of cracking is less important because it is variable, depending upon soil moisture, water regime, and type of land use. Therefore, instead of using duration of open cracks alone to place soils in Usterts or Uderts (if the soil is not flooding for a significant period of time), it may be appropriate if we add the moisture regime as another choice.

For example (Soil Taxonomy, 1975, page 377):

DC. Other Vertisols that have either or both of the following characteristics:

1. Have cracks that open and close one or more times during the year in most years, but remain open for as many as 90 cumulative days in most years.

2. Have an ustic moisture regime — Usterts

DD. Other Vertisols — Uderts

For the soils being flooded either by impounded water, overflows or irrigation for a significant part of the year (i.e. more than three months)

it can be placed into the Antraquic subgroup. We feel that the flooded Vertisols seldom qualify for the aquic moisture regime because most of the water covering the surface is impounded water, seldom fed by groundwater (Fig. 2). However, if these soils have fulfilled the requirement for an aquic moisture regime, a suborder Aquerts may be introduced.

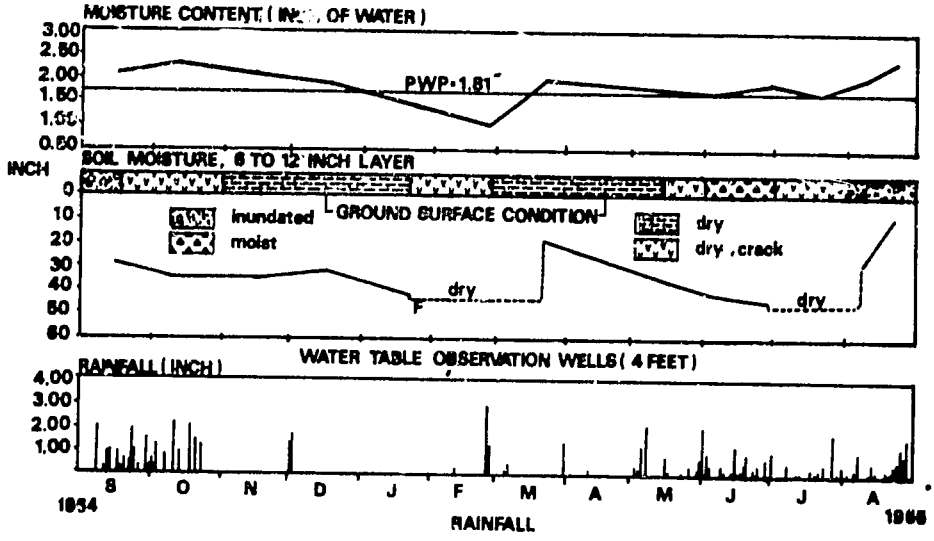

Fig. 2 Soil moisture and auxiliary data of a Vertisols being used for paddy rice

2. The chroma to distinguish the great group "Chromu" from "Pellu" should have a chroma, moist of more than 2, dominant in the matrix of some horizon in the upper 30 cm in more than half of each pedon.

3. To distinguish the vertic subgroup from Vertisols, the vertic subgroup should not have cracks as wide and deep as the Vertisols. However, cracks should be at least 30 cm deep in some parts at some time in most years. The other two requirements for vertic subgroup (i.e. Cole value and percent clay) still remain the same.

VERTISOLS IN RELATION TO LAND USE

Although Vertisols have posed various management problems if they remain under continuous utilization (Kanwar, 1982; Finch and Venkateswarlu, 1982; Virmani et al, 1982; Dudal and Moormann, 1966; Moormann and Breeman, 1978), most of the Thai Vertisols have been exclusively used for intensive cultivation. The following are the major land uses of Vertisols in Thailand:

Paddy (wetland) rice

Since most of the Thai Vertisols occur on flat to slightly depressed

topography with slopes generally not exceeding 1%, these soils have been exclusively used for paddy (wetland) rice. Retention or ponding of water in the paddy field is the result of bunding. In the central plain more than half of the Vertisols are under irrigation projects, whereas in the other areas, water is mostly supplied from overflow and/or precipitation.

Transplanted rice is the most common. The rice variety is locally variable; it may be the native variety or the hybrid ones which are modified from IRRI varieties. However, for the irrigated areas, the first rice crop in the rainy season (August-January) appears to be the native variety; the hybrid variety is grown as the second crop. Yields of paddy rice growing on various subgroups of Vertisols and other paddy soils are shown in Table 3.

Table 3. Rice yield of some Thai Vertisols and other related paddy soils.

Subgroup (particle size class = clayey)	Average rice yield (kg/ha) (under normal management)	Remarks
Aquentic Chromuderts	2,681 - 3,706	irrigated
Entic Pelluderts	2,775 - 3,487	irrigated
Typic Pelluderts	2,906 - 3,418	irrigated
Typic Pellusterts	2,550 - 2,962	irrigated
Vertic Tropaquepts	2,710 - 3,581	irrigated
Typic Tropaquepts	2,593 - 3,156	irrigated
Typic Tropaqualfs	2,443 - 3,312	irrigated

Yields of rice growing on the Vertisols range from 2,559 to 3,706 kg/ha, which is considered relatively productive. However, it should be noted that the Pellusterts seem to produce lower yields than the others.

The management problems of these soils for rice cultivation include the following:

Difficulties in cultivation and seed-bed preparation. As the general rule, the workability of the Vertisols is often unfavorable, resulting from soils that are either too wet or too dry. therefore, optimum moisture conditions for cultivation is required. According to field experience, once the rainy season sets in and the surface soil has been wetted for some period, plowing by tractor is generally possible. But for hand cultivation, the soil will be plowed after several inches of water covers the soil surface. In the case of second crops, plowing is unnecessary and impractical; the farmers only puddle the soils under wet conditions and then transplant.

Risk of water shortage. A great proportion of Vertisols are pluvial or marginal phreatic rice land (Moormann and Breemen, 1978). Where rice plants are mostly fed by rainwater, once a dry spell occurs and cracks open, in order to rewet the surface again, it takes not only time but also considerable amounts of rainwater. Therefore, under rainfed conditions rice yield is largely dependent upon climatic conditions.

Upland crops

The most common upland crops grown on Thai Vertisols are maize, cotton, banana, mung bean, and sorghum. Around farm houses in villages, tropical fruit trees such as coconut, mango, custard apple, and citrus fruit are also grown. Most of these crops are found to be cultivated on the Pellusterts or Chromusterts occurring on gently sloping terrain. Most crop yield data have not been available except for maize. Field trials conducted by the Land Classification Division (1976) showed that the average yield of maize ranged from 2,518 to 3,218 kg/ha under rainfed conditions and ordinary practices. Thus, the present system of management for growing maize on the Thai Vertisols seems to give satisfactory results and can compare favorably with the average yield of 3,197 kg/ha obtained under improved technology at ICRISAT in India (Kanwar et al., 1982).

Maize, mung bean, and sorghum are also grown as second crops after harvesting of wetland rice. However, sowing of these crops must be made at the right moisture status, i.e. neither too wet nor too dry. Droughtiness can also be problematic because of this post-rainy season sowing.

Problems concerning the use of these soils for cultivation of upland crops are also the same as elsewhere, but for the Thai Vertisols, the most serious management problems are waterlogging when it rains and moisture stress when there is a drought.

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VERTISOLS AND ASSOCIATED SOILS OF INDIA - DISTRIBUTION, MORPHOLOGY, CHEMISTRY, AND TAXONOMY

R.S. Murthy, J.C. Bhattacharjee, and R.J. Landey

ABSTRACT

Vertisols and associated soils occurring in the Peninsular India between N latitudes 8°45' and 26°0', and E longitudes 68°0' and 83°45' comprise 72.9 million ha, constituting nearly 22.2% of the total geographical area of the country. They have specific environmental characteristics, potential use, smectite mineralogy, a high coefficient of expansion and contraction setting up a steady churning process within the pedon, resulting in a process of vertical mixing and developing special features uncommon to other soils. The morphological characteristics of color, texture, structure, horizon boundary, microrelief and pedon characteristics are described. Distribution of clay content, organic carbon, and bulk density have certain definite trends. The plasma separation and illuviation of clay, the drainage characteristics of Chromusterts and Pellusterts and the aquic moisture regime have been adequately discussed. They require careful review and decisions to make the Vertisol taxonomy more rational.

INTRODUCTION

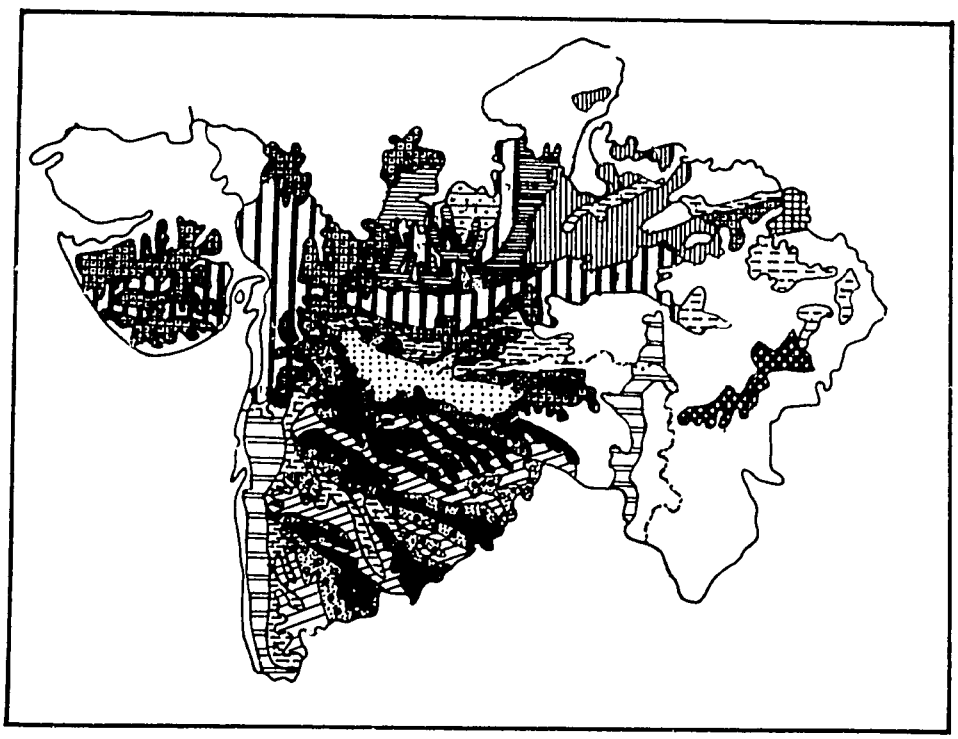
The Indian Vertisols are commonly known as "Black Soils" or "Regurs" originating from the Telugu language Nalla Reguds meaning "sticky, black earth" and are called by different names in different parts of the country. Due to the properties of cracking and swelling under dry and moist conditions respectively, cultivation and other cultural operations become difficult. Hence, many earlier workers were attracted to study the properties of Indian Vertisols. These soils constitute the most important soils of the states of Maharashtra, Madhya Pradesh, Gujarat, and North Karnataka. Considerable thought was given to the placement of these soils among the recognized great groups of the world. Many workers considered these soils nearer to the Tropical Chernozems. However, due to low organic matter content, placement of these soils under Chernozems was not acceptable to Indian scientists. These soils were found to be similar to the dark clays of South Africa. Wadia (1945) has compared the Black Soils of India with adobe clays of California. Oakes and Throp (1951) proposed the classification of dark clays of warm regions including Black Soils into a single group classified as "Grumosols". This was accepted by Simonson (1954) after examining Regurs in India. He observed a slow churning process generated by alternate shrinking and swelling of expanding layer lattice clay in soils inhibiting horizon differentiation.

Figure 1

VERTISOL AND ASSOCIATED SOILS SUBORDER ASSOCIATION

(GUJARAT, MAHARASHTRA, MADHYA PRADESH)

Km. 200 0 200 400 600 800 Km.



LEGEND

SUBORDER ASSOCIATION

- Orthents – Hilly and Misc. Land type
- Orthents – Ochrepts – Tropepts
- Orthents – Tropepts – Ochrepts
- Ochrepts – Usterts – Orthents
- Tropepts – Orthents
- Ochrepts – Usterts – Fluvents
- Usterts – Ochrepts
- Ochrepts – Usterts
- Usterts – Tropepts
- Tropepts – Fluvents
- Usterts – Ochrepts – Fluvents
- Ochrepts – Usterts – Ustalfs

MATERIALS AND METHODS

Distribution

Vertisols and associated soils occur mostly in the Peninsular India from 8°45' to 26°0' N and 68°0' to 83°45' E, covering an area of about 72.9 million hectares, constituting roughly 22.2% of the total geographical area of the country. The spatial distribution of major soilscapes of Vertisols and associated soils in India indicates that the latter occupies higher positions. Vertisols are mostly confined to the level plateau, valley depressions, and gently undulating piedmont plain, floodplain, deltaic plain, and coastal plain.

In view of their areal extent, the striking features of these soils are their specific environmental characteristics, potential use, and in regard to their smectitic mineralogy, high coefficient of expansion and contraction of vertical mixing and developing special features uncommon to other soils. An attempt has been made for an in-depth study. In such studies, the pedology of Vertisols and associated soils is prominently brought out to define the differentiating diagnostic properties of the various soils with aberrant properties according to taxonomic classification (Soil Survey Staff, 1975).

Extent

The areal extent of Vertisols and associated soils occurring in India is given below and shown in Fig. 1.

Order	Percent of the total Vertisols and associated soils		
1. Vertisol	38 (a)	Typic Chromustert	61%
	(b)	Typic Pellustert	39%
2. Inceptisol	37 (a)	Typic	4%
	(b)	Vertic	96%
3. Entisol	21	Mainly Ustorthent	
4. Aridisol	0.6	Salorthid	
5. Alfisol	0.4	Vertic Haplustalf	
6. Impurities (Mapping) Rock outcrops, miscellaneous land types, undifferentiated soils, etc.	3		

(Murthy et al., 1982)

Geomorphic and soil relationships

The soilscapes comprising Typic Ustorthent and vertic subgroups of Ustochrept/Ustropept dominantly occur on the plateau, pediment, and piedmont covering an area of about 20.5%, whereas the association of other soilscapes of vertic subgroups of Ustropepts and Ustochrepts and typic subgroups of Pellusterts/Chromusterts cover 13.9%. Association of typic subgroups of Pellusterts/Chromusterts and vertic subgroups of Ustropepts/Ustochrepts account for 12.6%; association of vertic subgroups of Ustropepts/Ustochrepts and Typic Ustorthents 12.4%, and Typic Pellusterts and Typic Chromusterts 5.5% of the area. The rest of the soils are classified as association of Vertisols and vertic subgroups of Halaquept, Haplaquept, Tropaquept and the saline phase of Vertisols.

Typic subgroups of Ustifluvents and typic subgroups of Salorthids occur in the low-lying areas along the coast and in the delta plains, whereas the vertic subgroups of Haplustalfs occur to a negligible extent in red soil terrain. The eroded landscapes with rock outcrops and undifferentiated soils on the higher elements of topography cover about 3% of the area.

In general, Vertisols with subgroups of Typic Chromusterts or Typic Pellusterts in association with vertic subgroups of Ustropepts and Ustochrepts are confined to the lower piedmont plain and floodplain, while vertic subgroups of Ustropepts and Ustochrepts form the major soils of pediment and upper piedmont or higher elements of topography.

Soils and their environment

Vertisols and associated soils are found to occur at elevations ranging from 300 to 900 m in Peninsular India, including erosional and depositional landforms. The form consists of residual hill ranges, dissected mesas, buttes and escarpments, and pediments. The latter is confined to piedmont plain, valley floor, intervening basin, and floodplains. Topographical variations play an important role in soil heterogeneity since they regulate the hydrological conditions, modifying the soil climate which in turn influences the pedogenic processes, morphological characteristics, and physicochemical properties.

Differences in mineralogical composition, texture, and composition of the rocks are important factors contributing to weathering and soil development. Nature and composition of rocks frequently induce the formation of secondary minerals and influence ionic composition of a soil solution system. Vertisols are mainly formed from basalt, chiefly augite basalt. Its texture ranges from vitreous basalt at one extreme to coarse-grained dolerite at the other. Basalt, norite, and metamorphosed Dharwarian rocks are the main sources from which Black Soils of southern India are formed. Abundance of alkaline earths in the parent material appears to be the sine qua non for the formation of Vertisols since it maintains a high concentration of bases in alkaline medium and blocks the formation of the kaolinite and, thus, possibly helps the formation of montmorillonite.

Padole (1955) has reported differences in parent material responsible for changes in physical and chemical composition of Vertisols of Madhya

Pradesh while Tamhane and Nam Joshi (1959) failed to observe any marked influences. Black Soils are also reported to have derived from weathered sodalime feldspars which are responsible for yielding heavy texture (Ramiah and Reghavendrachar, 1936). They are also reported to have been formed from marine alluvium (Bhattacharjee et al., 1979). From the above reports, it may be concluded that for the genesis of Black Soils, presence of a high proportion of alkaline earth in the weathering complex is essential. Equally important is the alignment of the particles of the parent material by which leaching and removal of alkaline earths are restricted.

RESULTS AND DISCUSSIONS

Morphology

Color. Morphology of Vertisols (Table 1) reveals that Vertisols are dark grayish-brown in color with hues of 10YR and 2.5Y, dry values 4 and 5 and moist value 3 and occasionally 2. Chroma varies from 3 to [illegible] for both moist and dry soils. Interdigitating mottle colors are dark yellowish-brown, 10YR 3/4 and 4/4 and mostly noticed in the AC horizon as fine to coarse tongues. Mottling is noticed in some soils having neutral color in hue 2.5Y as evidence of poor drainage. Interdigitating colors which are absent in vertic subgroups demarcate clearly the Vertisols from vertic subgroups.

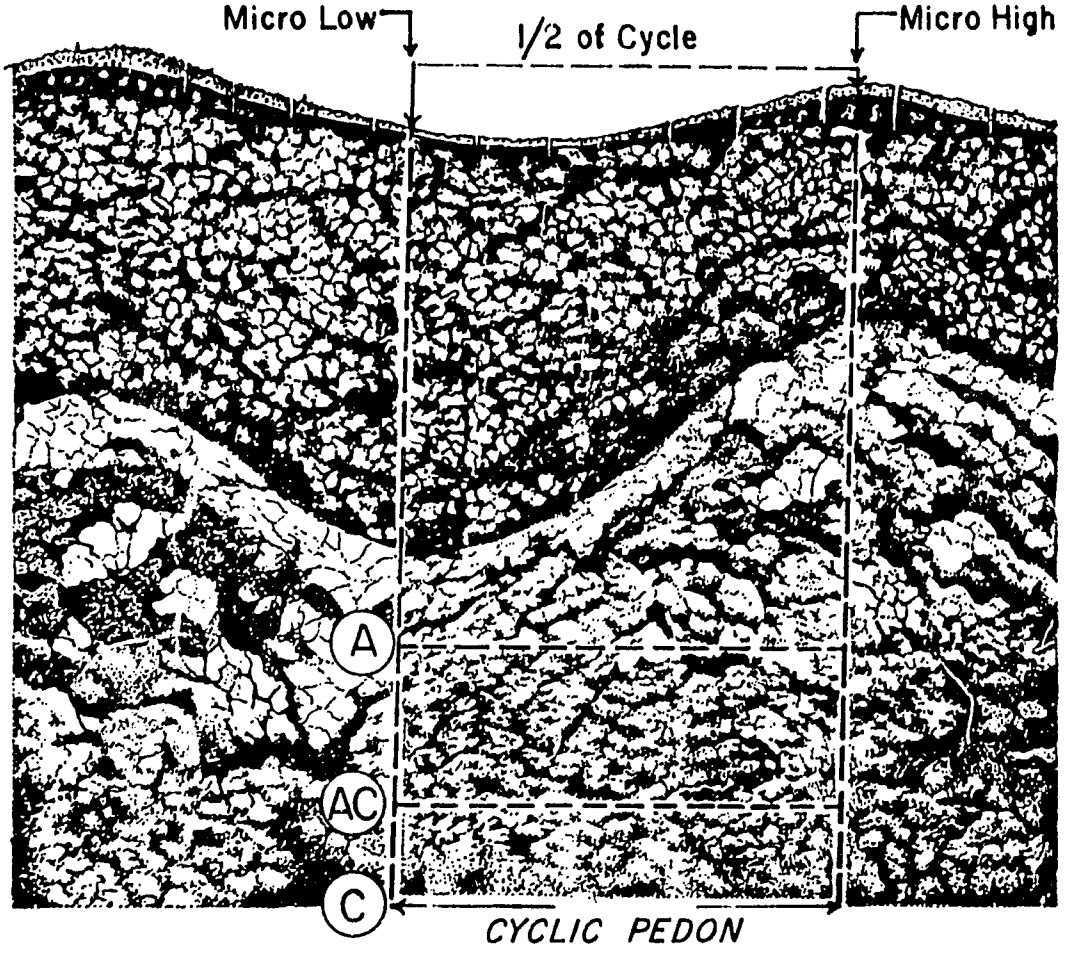
Structure. Structure in Vertisols, coarse prismatic separating to mostly coarse angular blocky peds, faces of which are smoothened and inclined to 30° with horizontal axis, shows the evidence of the high shrinking/swelling nature of clay. In associated soils, it varies from medium moderate subangular blocky to coarse strong angular blocky with pressure faces showing the evidence of a troweling effect. Prominence of slickensides and orientation of shear planes and intersecting slickensides forming parallelepiped structural aggregates are present in the subsoil layers of Vertisols. The associated soils do not exhibit such features beside pressure faces of structural peds. However, instances are not uncommon in vertic subgroups where the subsoil layers transitional to C horizon exhibit slickensides close enough to intersect but not actually intersecting. Hence, this may be taken as morphological criteria for differentiating Vertisols from the vertic subgroups in field study.

Pedon. Cyclic movement causes vertical mixing of materials and results in a high degree of uniformity while the associated soils exhibit an isotropic property in the profile with depth. The associated soils of vertic subgroups may have ABC profiles and thickness of horizon uniform within the pedon, somewhat running parallel to surface. At some places, shallow associates may have only A horizon directly overlying Ac or C horizon. Vertisols mostly exhibit variable depth ofhorizons due to cyclic movement. This again is a phenomenal distinction between Vertisols and vertic subgroups (Bhattacharjee et al., 1977, 1982).

Horizon boundary. There is a distinct contrast in the boundaries of Vertisols and associated soils. Mostly clear and gradual boundaries with smooth and wavy topography have been recognized in vertic subgroups, while in Vertisols recognition of topography of lower boundary of cyclic or intermittent horizon is somewhat difficult. However, apparent topography

Figure 2.

SCHEMATIC DIAGRAM OF IDEAL VERTISOL PROFILE IN INDIA



<1m. - Small cyclic Pedon

1m.- 2m. - Medium cyclic Pedon

2m.-3·5m.- Large cyclic Pedon

identified in terms of amplitude has been recognized (Dudal, 1965; Bartelli, 1971) as low, medium and high having the shape as tongued, wavy and smooth (Bhattacharjee et al., 1977) may be included as a distinct differentiating criterion which is related with cyclic mass movement. As such, it would necessitate modifying the style of describing morphological features, especially the horizon boundary in Vertisols.

Open shrinkage cracks of 2 to 5 cm tapering through depth constitute the normal surface feature. The cracking pattern, both vertical and horizontal, is observed in vertic subgroups as well as in Vertisols. But it is significant to note that in Vertisols, the pattern of cracking shows its oblique nature and runs along the slickensides while in vertic subgroups, vertical cracks run straight with the depth of the pedon.

Microrelief. Gilgai microrelief is invariably observed in Vertisols; at places, weak development of gilgai relief is also noticed in vertic subgroups.

In the placement of soils under Vertisols, the differentiating features in agreement to the observations of Bhattacharjee et al. (1982) should be (i) gilgai microrelief, and (ii) intersecting slickensides within 30 cm of the surface. This is also to stress that the soils not fulfilling these criteria should be considered soils other than Vertisols.

Plasma separation and illuviation of clay. The slow process of haploidization due to argillipedoturbation makes the illuviation layer lattice clay somewhat impossible (Buursink, 1971). There are few reports of clay illuviation based on micromorphological findings (Jongerius and Bonfils, 1964). Measuring incipient flocculation ratio, Osman and Eswaran (1973) observed that clay in Vertisols can move but clay cutans observed in thin section were found disrupted and assimilated into the matrix due to pedoturbation. Iron and manganese become mobile based on pH-Eh in Vertisols. In certain zones, pH is mainly depletion and accumulation of these elements. In the deeper subsoil of Vertisols, Eh is reduced, and liberated Fe^{2+} and Mn move with depth and accumulate on bicunate faces of peds as Ferran or Mangans. The infillings of clay through cracks get pressed between soil masses due to the high shrink-swell potential of montmorillonitic clay. The ferran and mangan or organo-ferran/mangan coat the surfaces of parallelepipeds. While the surface becomes dry, the dried papules look like dark fish scale with color different from ped-interior. Many times workers mistake it for clay cutans and group the soils as Pellustollic.

Favorable soil-forming processes lead to Vertisol even in:

1. high rainfall regions in tropics on ultrabasic rocks or on mildly basic materials on accumulative basin;

2. temperate climate on Ca-Mg clays and marl; and

3. arid climate in depressions that are periodically flooded.

<u>Preponderance of smectite minerals</u>

1. Montmorillonite develops with very high Si/Al even >5 molar ratio in high pH in presence of Ca^{2+}, Mg^{2+}, and Na^{+}.

Table 1. Morphological characteristics of Typic Chromusterts/Typic Pellusterts and Vertic Ustropepts/Vertic Ustochrepts.

Horizon	Depth in cm	Color		Texture	Structure		Consistence	Boundary	Other features
		Dry	Moist		Tertiary	Secondary			
					Typic Chromustert				
Ap	0-15	10YR 3/3	10YR 3/3	C	3c Pr	2m sbk	dh, mfi, ws, wp	ds	Fine lime nodules, es; open cracks (2-4 cm); gilgai with linear frequency of microknoll and micro-depression
A12	15-50	10YR 3/3	10YR 3/2	C	3c Pr	2c abk	ch, mvfi, wvs, wp	ds	Medium lime nodules (1.95-2.0 cm), es; cracks (1-2 cm); shiny pressure faces on peds
A13	50-95	-	10YR 3/2	C	Intersect-int slicken-sides forming parallel-epipeds	3c abk	-do-	cs	Medium lime nodules, es; cracks (1 cm) up to 90 cm; parallelepipeds with long axes tilted 35° from horizontal; abk with shiny pressure faces.
A14	95-130	-	10YR 3/2	C	-do-	-do-	-do-	cw	Many lime nodules, es; parallelepipeds with long axes tilted 40-45° from horizontal; abk with shiny pressure faces
AC	130-165	-	10YR 4/3 and 10YR 3/2	C	-do-	-do-	-do-	ds	Many lime nodules, es; parallelepipeds with long axes tilted 45° from horizontal; abk with shiny pressure faces.
C	165-180	-	10YR 4/3 and 10YR 3/3	C	Intersect-ing slicken-sides	2m abk	dh, mfi, ws, wp	-	Many lime nodules, ev; many soft powdery lime patches.

Table 1 continued

					Typic Pellustert				
Ap	0-20	10YR 4/1	10YR 3/1.5	C	2c Pr	2m sbk	dsh, mfr. ws, wp	cs	2 cm pulverized surface mulch, es; gilgai relief, microknoll, 10 cm over micro depression; random, sink holes open cracks 2 - 5 cm wide segregated lime nodules, powdery lime.
A12	20-40	-	10YR 3/1	C	3c Pr	2m sbk	dh, mfi, ws, wp	gs	f.m. lime concretions, es; quartz gravels; shiny pressure faces.
A13	40-60	-	10YR 2.5/1	C	Intersecting slickensides, coarse parallelepiped	3c abk	dvh, mvfi, wvs, wvp	gw	shiny pressure faces, m-c lime concretions, es; fine oblique imped and exped pores
A14	60-90	-	10YR 2.5/1	C	-do-	3c abk	-do-	cw	coarse lime concretions, violently effervescent, very fine exped pores
Ac	90-130	-	10YR 3/1	C	-do-	3c abk	-do-	gw	common coarse distinct, 2.5Y 2.5/2 and 2.5YR 5/4 mottles which are interdigitating cores of C and A14
C	130-180	-	2.5Y 5.5/4	C	-do-	3c abk	-do-	-	coarse faint 2.5Y 4/2 mottles

Table 1 continued

Horizon	Depth in cm	Color Dry	Color Moist	Texture	Structure Tertiary	Structure Secondary	Consistence	Boundary	Other features
				Vertic Ustropept/Vertic Ustochrept					
Ap	0-12	10YR 4/2	10YR 3/2	C	2c Pr	2m abk	dh, mfi, ws, wp	ds	many lime nodules, es; open cracks (0.5-1.5 cm)
B21	12-48	10YR 4/3	10YR 3/3	C	1c Pr	3c abk	-do-	ds	many fine conc, es; cracks (0.5 cm) up to 45 cm; pressure faces on peds
B22	48-88	-	10YR 3/3	C	slickensides	3c abk	-do-	gs	many medium lime nodules, es; abk with shiny pressure faces (stress cutan)
B3	88-110	-	10YR 4/3	C	-	3m sbk	-do-	gs	many medium and fine lime nodules; ev.
C	110-130	-	10YR 6/3 and 10YR 7/2	Cl	-	1m sbk	dsh, mfr, wss, wps	-	many medium lime nodules and powdery lime; ev.

Symbols used are the same given in Soil Survey Manual, U.S.D.A. Handbook No. 18, 1951, p. 139-140.

2. The quantum of available water and hence the duration of the growing period, as well as the various soil management and crop husbandry practices, are not identical. Hence, it was suggested to create udic, typic, and aridic subgroups in the great groups Chromusterts and Pellusterts.

3. Vertisols are usually deficient in N_2 and low in humus. Immense yield increment can be attained by application of N_2-fertilizers, particularly in the rainy season.

4. P_2O_5, though appearing adequate at the present level of crop yields, may become limiting with bigger harvests made possible by new technologies. However, unlike N_2, P_2O_5 poses severe problems because of very low recovery of fertilizer P_2O_5.

5. The basic principles thus evolved have widespread applicability, though specific management systems will have to be developed taking into account the local situations.

According to Soil Taxonomy, Chromusterts are supposed to be better drained than Pellusterts, which are poorly drained. This point needs further elaboration and discussion.

(i) Nimone series is Typic Chromustert but imperfectly drained, still having chroma 2.

(ii) Umbraj series is Udic Chromustert but poorly drained, still having chroma 2.

(iii) Dhandhuka series is Typic Chromustert but poorly drained; chroma is 2.

(iv) Malegaon series on level plateau with moderate drainage; chroma is 1.

(v) Achmatti series on level basin, imperfectly drained; chroma is 1.

(vi) Raichur series on gently sloping alluvial plain moderately well-drained; chroma is 1.

Chroma and pell are encountered in different situations of drainage and topography. Thus, existing classification is not entirely satisfactory. Since drainage status of Vertisols is very important for land use, it should be reflected at a much higher level of classification than hitherto understood. Therefore, there is a strong case for creation of "Aqert" suborder for very poorly drained soils.

Aquic moisture regime. This implies a reducing regime that is virtually free of dissolved oxygen because the soil is saturated by groundwater or by water of the capillary fringe. Aquic must be a reducing one.

Some soil horizons at times are saturated with water while dissolved oxygen is present, either because the water is moving or because the environment is unfavorable for microorganisms. Such a regime is not considered aquic. For differentiation in the highest categories of soils that have

an aquic regime, the whole soil must be saturated. The soil is considered to be saturated if water stands in an unlined borehole at such a shallow depth that the capillary fringe reaches the soil surface except in noncapillary pores.

Chemistry

The texture in Vertisols ranges from clay to silty clay, at places silty clay loam to clay loam, the clay content ranging from 40-60%, and occasionally 80%. The associated vertic subgroups have a higher content of clay which tends to increase to a particular depth and decrease thereafter. It is also interesting to observe that the clay distribution in Vertisols is somewhat uniform. The ratio of CEC to clay is around 1, indicating dominance of smectite in the exchange complex. In vertic subgroups, it is between 0.5 and 1, indicating illitic or mixed to montmorillonitic mineralogy.

Organic carbon content is low, ranging from 0.3 to 0.7 and its distribution is more or less uniform, but in associated soils there is a regular decrease with depth. pH of the soils is mildly to moderately alkaline and varies from 7.4 to 8.5 depending upon the nature of parent material, base status, climate, and topographic situation. At places it may be strongly to very strongly alkaline.

Bulk density of soil between cracks, with dry clod method, ranges from 1.5 to 1.8 g/cc. However, higher values ranging between 2 and 2.2 have also been observed. In vertic subgroups, it ranges from 1.4 to 1.7 g/cc.

Taxonomy

Vertisols occur in areas experiencing monsoonic climate, mostly under semiarid and subhumid conditions. However, small pockets under arid climate are also met with. Overhead climate is hot and dry, and intense summer is followed by a specific rainy period with rainfall ranging from 400-1600 mm. Mean maximum daily temperatures range from 36° to 42°C in April and May, and mean minimum temperatures range from 10° to 24°C in December and January. The difference between mean winter and mean summer temperatures becomes wide in the north beyond 20°N latitude and narrower below. Normal rain sets in the last part of June and extends to September. At places, in the southern part of India, rainfall is received from September to December. In most of the areas, the temperature being high, PE exceeds precipitation, indicating incomplete leaching. Due to alternate brief wet and prolonged dry conditions in this part, any process other than calcification seems to be inoperative resulting in high base saturation with concentration of free lime in the matrix either in hard nodular form or as powdery mass. Karale et al. (1968) have emphasized the climatic factor which plays a decisive role in characterization of soils due to its influence on weathering.

The Vertisols in India have been classified as Chromusterts/Pellusterts under the existing definition, in view of the climatic variations with respect to the volume of annual precipitation, potential evapotranspiration,

number of dry and humid months, humidity index, aridity index and moisture index, and moisture storage. It is felt that there is need for further subdivision of the Ustic regime at the great group level to Aridic Ustic, Typic Ustic, and Udic Ustic subgroups for more meaningful placement of Vertisols linking utility potentials in agreement with Smith (1979) and Murthy et al. (1982).

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MINERALOGY OF ARIDISOLS AND VERTISOLS

Ben F. Hajek

ARIDISOLS

Aridisols are soils with aridic moisture regimes, with more development than Entisols or if more moist than aridic, there must be a saline horizon. Aridisols have ochric epipedons and usually argillic, cambic, or natric subsurface horizons. Calci, petrocalci, gypsic, petrogypsic, salic, and duripan subsurface horizons must be present if there is no argillic, natric, or cambic layer. These horizons often are present in addition to argillic, natric, and cambic, being used to class soils at the great group and subgroup categories (Soil Survey Staff, 1975; Allen, 1977). Aridisols have alkaline soil environments frequently with significantly large amounts of carbonates. However, they certainly can be noncalcareous to depths of one meter.

On the basis of climate, arid regions occupy 36% of the earth's surface; on the basis of vegetation, 35% (Buol et al., 1980). Arid land soils are concentrated between 10° and 15° N and 15° and 50°S. The major continuous area begins in Africa and goes through the Sahara and Arabian peninsula to Eastern Mongolia. This is about 13,000 km. Africa has the largest area; Australia the largest percentage. Aridisols are the only order confined to arid regions by definition. They comprise about 36% of soils in arid regions and about 11% of the world land area (Dregne, 1976).

Mineralogy of Aridisols

Detailed studies of mineralogy of arid land are relatively recent. Marshall (1977) states that because of the low intensity of weathering, the following is expected: (1) no complete throughput of water, (2) mineralogy often reflects the mineralogy of the parent material, and (3) accumulation of all weathering products at various depths in the series control section. The most obvious products of weathering arrested in the profile are carbonates, sulfates (Ca & Na), and halides. If secondary aluminosilicates are considered in respect to stability diagrams, several statements can be made about these minerals (Garrels and Christ, 1965; Lindsay, 1979) in arid soil environments.

Moderately high sodium and high pH favor formation of or stability of Na-montmorillonite or Na-beidellite depending on the amount of Mg in solution. High Na and high Mg favor analcime plus triocthedral smectite. Very high Na alone gives analcime. Illite (clay mica) is stable under moderate K^+/H^+ and moderate Mg. Very high Mg should favor the formation of attapulgite and

sepiolite. Montmorillonite, biedellite, illite, analcime, attapulgite (polygorskite), and sepiolite could form by synthesis as weathering products from feldspars, mica, and ferromagnesian minerals. All of these minerals have been reported in Aridisols. Although kaolinite is usually present, it is not forming under present arid soil environments.

Buol (1965) in a review of weathering processes in arid regions concluded that evidence for translocation existed, especially the presence of cliche and calci layers. The clay mineralogy in arid soils is probably controlled more by parent material than by clay weathering during pedogenesis. The theoretical possibilities pointed out by Garrel and Christ (1965) and Marshall (1977) are consistent with Buol's (1965) conclusions based on reported data.

Montmorillonite is the most frequently reported dominant mineral in the clay fraction of Aridisols (Gile and Grossman, 1979; Aba-Husayn et al., 1980; Barshad et al., 1956; Van Der Merwe and Heystek, 1955; Wildung, 1977; Al-Rawi et al., 1969; Paredes and Buol, 1981; Gal et al., 1974). Clay mica (illite) was the most frequently reported clay mineral. Illite was present in essentially all Aridisols from all parts of the world (Sidku and Gilkes, 1977). Kaolinite is usually present in most arid clays. There are few notable exceptions for some soils from North America (Mclean et al., 1972), Iraq (Al-Rawi et al., 1969), and Iran (Abtahi, 1977). Vermiculite was found to be a major component in a Calciorthid, two Camborthids, and two Natrargids in Iran (Mahjoory, 1979; Al-Rawi et al., 1969; Mahjoory, 1975). Mixed layer, interstratified systems are often detected. It is difficult to quantitate, especially since some component may be included as a single component (eq. mica by total K_2O).

Many and often quantitatively significant amounts of polygorskite (attapulgite) and sepiolite are reported in Aridisols from many parts of the world. Quantities in excess of 20% are reported (Abtahi, 1977, 1980; Mclean, 1972; Al-Rawi et al., 1969; Barshad et al., 1956; Zelazny and Calhoun, 1977; Elgabaly, 1962).

SUMMARY

As pointed out by others (Dregne, 1975; Buol, 1965), illite is the most common clay mineral in arid soil. Although its frequency of occurrence is greatest, it is usually reported secondary in abundance. Most frequently, smectite dominates the clay fraction in arid regions other than in Australia (Stace et al., 1968) where illite, kaolinite, and interstratified minerals are usually reported.

Considering placement into mineralogical families, in clayey soils (>35% clay) montmorillonitic and mixed classes will essentially include all Argids and Camborthids. Essentially all Aridisols in loamy families are classed in mixed mineralogy families (Table 1).

Calci- and Paleorthids in North America have a significant number of series in carbonatic families. The place for polygorskite (attapulgite) and sepiolite has not been determined, however, these minerals seem to occur most frequently in Calci- and Salorthids.

Although halides and sulfates are frequently significantly components of Aridisols, concentrations are often in terms of soluble components and not percent of total mineral matter (Doner and Lynn, 1977).

Table 1. Series in Aridisol Mineralogical Families of the United States and Puerto Rico, August 1981.

	Clayey						Loamy	
	Montmorin	Illitic			Carbonitc		Mixed	
		Mixed		Kaolin		Gypsic		Siliceous
Duragids	32	3					64	
Haplardid	71	32					332	
Nadurargi	11	1					10	
Natragid	61	7	1		1		61	
Paleargid	32	2			1		17	
Calciorthics		1			43		191	
Camborthids		17	1	1	3	1	208	1
Durorthids					4		88	
Gypsiorthids					4	11	12	
Paleorthids					20		29	
Salorthid	3	4				1	17	
Total	210	67	2	1	76	13	1,028	1

VERTISOLS

Vertisols are clayey soils that shrink and swell to the extent that the cracks are evident at a depth of 50 cm and have evidence of soil movement in the form of slickensides, gilgai, and wedge-shaped structural aggregates. Other than the distribution of organic matter, the characteristics of horizons change little with depth (Soil Survey Staff, 1975).

Large areas occur in Australia, India, Sudan, Venezuela, Chad, Ghana, Cuba, Puerto Rico, United States, and Taiwan. These soils are locally important, presenting many unique problems in use and management. High clay content, expanding lattice clays, and saturated permeability are of primary concerns for both engineering and agricultural uses (Buol et al., 1980; Allen, 1977).

Mineralogy of Vertisols[1]

The mineralogy of Vertisols is usually dominated by smectite (Soil Taxonomy) although a few have been reported as kaolinitic. Only three mineralogical families have been established in the United States, Puerto Rico, and the Virgin Islands: montmorillonitic, mixed, and two series in kaolinitic (Table 2). Of the 188 series recognized, 172 are montmorillonitic.

Table 2. Series in Vertisol Mineralogical Families by Great Groups (Soil Series of the United States, Puerto Rico, and The Virgin Islands. August, 1981).

	Montmorillonitic	Mixed	Kaolinitic
Torrerts	8	2	0
Chromuderts	13	3	0
Pelluderts	12	0	0
Chromusterts	48	6	2
Pellusterts	36	3	0
Chromoxererts	43	0	0
Pelloxererts	12	0	0
Total	172	14	2

The smectites are usually montmorillonite or beidellite (Sawhney and Jackson, 1958, and unpublished data, B.F. Hajek). The smectite content is usually high and in some soils will comprise essentially all of the < 0.1μm clay (Carson and Dixon, 1972).

A typical Vertisol will have from 40-60% clay. Of this, about half the clay will be finer than 0.1μm. From 40-50% of the clay is smectite although more than 70% has been reported (Fitzpatrick and Leroux, 1977). About 15-30% will be kaolinitic, with mica often comprising around 10%.

[1]Portions of this report were obtained from a report by J.B. Dixon. Mineralogy of Vertisols. Department of Soil and Crop Sciences, Texas A&M Univ., College Station, Texas, U.S.A.

Kaolinite appears to be due partly to weathering from smectite and often inherited from parent material (Dixon and Nash, 1968; Dudal, 1965; Fitzpatrick and LeRoux, 1977; Kantor and Schwertmann, 1974). Kaolinite can be the dominant mineral but will be classed as mixed because of the >10 percent smectite criteria. Significant amounts of kaolinite were found in some Vertisol in Venezuela (Table 3).

Vermiculite is also present in these soils from Venezuela (Table 3) and other Vertisols (Carson and Dixon, 1972; Karathanasis and Hajek, 1982).

Mica is present in small amounts. Quantities are usually based on the amount of total K_2O (Mohr et al., 1972; Carson and Dixon, 1972).

Chlorite has been reported in Vertisols from Turkey (Güzel and Wilson, 1981), three soils from South Africa, and in Vertisols from Alabama and Mississippi, U.S.A. (Dixon and Nash, 1968).

Other minerals of relatively minor extent and of little toxonomic weight are: free iron oxides, feldspars, pyroxenes, quartz, amphiboles, and olivine.

Carbonates, especially calcium carbonate, is frequently reported as a significant mineral. Calcite can be present in the form of hard and soft concretions and as free carbonate as part of the entire soil matrix (McKee and Hajek, 1973).

The persistence of carbonate in Vertisols is well established. The pH control exhibited by this mineral and the abundance of calcite suggests that more study is needed, and perhaps consideration should be given to calcite as criteria for classes.

Quantitative Mineraology - Aridisols and Vertisols

The amount of reliable quantitative clay mineral analysis of soil clays is relatively scarce, especially prior to about 1960. Methods that give data that is suitable for soil classification and for many interpretations are now available to many soil scientists. These include X-ray diffraction, X-ray emission, thermal analysis, chemical (CEC, CO_2, total K) atomic absorption, surface area, and others. Excellent approximate data can be obtained by careful step-heating and weighing and from cation exchange capacity measurements. X-ray diffraction peak height quantities usually need to be supplemented by at least cation exchange capacity or thermal data.

Table 3. Mineralogical composition of Clay Fractions from some Vertisols in Venezuela. Samples from Dr. Juan A. Comerma. CENIAP.

DEPTHS	Minerals									
	HIV	SM+VR	MICA	KLN	GBS	GTH	QRZ	INTG	CLC	TOTL
-cm-	%									
SOIL SERIES : El Palmar										
0- 10	-	32*	31	30	-	-	5	-	-	98
10- 40	-	30*	32	32	-	-	5	-	-	99
40- 80	-	32*	27	33	-	-	4	-	-	96
80-210	-	29*	27	34	-	-	3	-	-	93
(*primarily vermiculite)										
SOIL SERIES : La Guajira										
0- 10	-	39	20	30	-	-	5	-	-	94
40- 80	-	40	21	29	-	-	3	-	-	93
80-110	-	37	22	30	-	-	3	-	-	92
140-155	-	39	22	30	-	-	3	-	-	94
SOIL SERIES : Lagunillas										
0- 10	-	28	18	51	-	-	-	1	-	98
30- 50	-	26	18	49	-	-	4	-	-	97
120-150	-	29	18	44	-	-	-	1	-	92
SOIL SERIES : Valle Hermoso										
0- 20	-	45	18	24	-	-	-	10	-	97
35- 52	17	44	17	15	-	-	-	7	-	100
90-110	10	44	18	19	-	-	-	8	-	99
110-130	12	40	18	19	-	-	-	11	-	100
SOIL SERIES : Pedon : Exp. Station, Central Venezuela										
0- 18	-	34	16	37	-	3	4	-	-	94
38-100	-	34	17	37	-	4	4	-	-	96
130-200	-	38	18	33	-	2	3	-	-	94

SUMMARY

The mineral smectite is dominant in most Vertisols of the world. The expansion characteristics of smectite and the usual abundant fine particle size of this mineral give soils the volume change needed to be Vertic. Even if other minerals dominate, smectite usually is present, and fine clay is a significant part of the soil. Kaolinite is usually detected as the second most abundant mineral with a small amount of mica (illite) and free iron. Other clay minerals include vermiculite and chlorite. Calcite is significant in many Vertisols. The other minerals reported are usually inherent to the parent material.

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RELATIONSHIPS BETWEEN MORPHOLOGICAL PROPERTIES AND DRAINAGE IN VERTISOLS

W.A. Blokhuis

ABSTRACT

Morphological properties that could indicate poor drainage in Vertisols have been studied in profile and site descriptions from various countries. Some trends that became apparent are as follows.

Low chroma in combination with length of flooding is a reliable indicator of poor drainage. The low chroma of some residual Vertisols on hillslopes may be caused by very slow internal drainage, or it is an inherited feature, or both. Yellow hues do sometimes indicate wet conditions, but not consistently so. Mottles in the surface soil reflect waterlogging conditions, but high pH in poorly drained sites prevents surface soil mottling. Mottling in the lower part of the solum is due to either a transient perched water table, groundwater in a permeable substratum, or "in situ" weathering of primary minerals.

The feasibility of a groundwater table in Vertisols is discussed, and it is postulated that groundwater tables cannot be defined. Transient perched water tables are feasible at the sites of cracks.

INTRODUCTION

Morphological properties that are related to poor drainage are generally those that are supposed to be evidence of reducing conditions in the soil for some part of the year. Dudal (1965) lists the following examples of such properties: very low chromas, neutral or gley colors, yellowish hues and mottling at moderate depths.

In the 7th Approximation (Soil Survey Staff, 1960) Vertisols with "characteristics associated with periodic wetness" were placed in the suborder Aquerts. Diagnostic criteria were:

- "chromas of less than 1.5 throughout the upper 30 cm," and/or
- "distinct or prominent mottling within the surface 73 cm."

In the revised edition of 1967, the criterion on chroma was downgraded to the categorical level of the great group, that on mottling to the subgroup.

In the final edition of 1975 (Soil Survey Staff, 1975) "soil moisture regimes" were defined. These presumed the moistening and movement of water from the surface downwards along a continuous, more or less horizontal, front. Such soil moisture regimes could not be identified in Vertisols, that are characterized by a very low hydraulic conductivity of the soil material and at the same time by the presence of wide and deep cracks that allow a rapid, but short-lived and spotwise deep penetration of water. The bore-hole method that is used to identify an aquic soil moisture regime does not work in Vertisols, so a suborder Aquerts could not be defined. Consequently, criteria for periodic wetness remained at the same categorical levels: low chroma for great groups (in most suborders) and mottling for subgroups (in some great groups).

In February, 1981, ICOMERT raised the question whether the chroma-distinction at the great group level ("Pellis" versus "Chromic") did in fact separate the poorly drained Vertisols from the better-drained ones (as it was supposed to do): many "Chromic" Vertisols appeared to be poorly or very poorly drained. ICOMERT suggested defining "poorly or very poorly drained" Vertisols as those that have "water at the surface for 3 or more months during the year." If that concept of "poorly or very poorly drained" could be accepted for an "aquic moisture regime" in Vertisols, a suborder Aquerts could be defined.

Guy D. Smith suggested including slope as an additional diagnostic property ("Proposed Amendments to Soil Taxonomy," Draft; May, 1978). The definition of Chromuderts and Chromusterts was to be enlarged with: "and have slopes of 1 per cent or more," and that of Pelluderts and Pellusterts with: "or have slopes of less than 1 per cent."

The question of how drainage condition corresponds with the criteria used in Soil Taxonomy is the subject of this paper. Drainage condition is a complex property: it depends on climate, evapotranspiration, topography and soil; the movement of water (or lack of it) in a heavy clay soil with shrink-swell properties is of particular importance.

MATERIALS AND METHODS

Morphological properties of Vertisols, and especially those that are (supposed to be) related to soil drainage, were compared with site characteristics, notably parent material, slope, geomorphic position, rainfall and other climatic data, and, if appropriate, hydrological characteristics such as groundwater level and length of flooding. The data were taken from published sources, soil survey reports and author observations, the latter mainly from the Sudan.

This "survey" is, of course, far from complete, and probably not representative for all Vertisols. However, some trends have emerged, and, given the relative uniform morphology of the Vertisol order (Soil Survey Staff, 1975), these are probably valid for Vertisols in other regions also.

MORPHOLOGICAL INDICATIONS OF HYDROMORPHIC CONDITIONS IN VERTISOLS

Low chroma in relation to slope and length of flooding

Slope is not a useful characteristic for separating sites with "Pellic" from those with "Chromic" Vertisols. In the Central clay plain of the Sudan, where slopes are generally below 0.5%, and often below 0.05%, "Chromic" Vertisols dominate. "Chromic" Vertisols on sites without perceptible slope also occur in the Gharb plain, Morocco (Bryssine, 1967) and in Chad (Pias, 1970; Bocquier et al., 1968; Audrey, 1968).

In slightly concave, depressional sites subject to flooding, or to more prolonged flooding than datum sites[1], the occurrence of "Pellic" Vertisols is more consistent, provided the amount of rainfall and/or flooding is sufficient. In the Central Sudan clay plain, "Pellic" Vertisols are restricted to distinct depressions that also carry a vegetation that reflects waterlogging conditions. The chroma-limit as defined in Soil Taxonomy works well in the Sudan in areas with rainfall over about 600 mm: "Pellic" Vertisols in depressional sites have chromas 1.5 or 1; "Chromic" Vertisols on datum sites have chromas 2; higher chromas do occur but seem to be related to provenance of the clays rather than to better drainage.

In Venezuela, a separation at chroma 1.5 appeared to be less operational. Comerma and Luque (1982) selected 77 profiles of well-characterized Vertisols, of which 40 were Pellusterts and 37 Chromusterts. Not only almost all of the Pellusterts but also nearly half of the Chromusterts occurred on sites that had water at the surface of the soil for three months or more. If, however, the color criterion was shifted from "1.5 or less" to "2 or less," the latter category occurred almost exclusively on flooded sites whereas the Vertisols with chroma over 2 occupied nonflooded sites.

The use of the chroma-criterion to indicate poor drainage is made complicated by the occurrence of residual "Pellic" Vertisols on sloping terrain; in the Sudan, e.g. on basalt in the Gedaref area (Beinroth and Dümmler, 1965; Knibbe, 1964) and on basic metamorphic rock in the Southern Kenana (Mohr et al., 1972). Similar observations were made in the Canary Islands (Fernandez Caldas et al., 1981) and have been mentioned by Dudal (1965). We do not know whether the low chroma is inherited from, or at least influenced by, the parent rock or whether the internal drainage in these soils is so slow

[1] Smith (1949) used the term "datum site" to indicate a level area that neither receives discharges from higher ground nor loses water by runoff.

that waterlogging conditions exist even when there is runoff. Waterlogging could be due to an impermeable rock layer at rather shallow depth, or to the formation of smectitic clay in the saprolite.

Profile and site data given by Dudal (1965) show that "Pellic" Vertisols on sloping terrain are more common in high-rainfall regions than in semi-arid regions. In some of these cases there may be a combined influence of both parent rock and relatively high rainfall. High rainfall and flooding have the same effect on many properties of Vertisols.

Hue 2.5Y or 5Y

Most Vertisols have a hue 10YR. Some have hues 2.5Y or even 5Y, and there are indications that the yellow hues indicate wetter conditions, even when chromas remain 2 or higher. Bunting and Lea (1962), working in the Kenana area of the Sudan, found that soils in large depressions at the end of long continuous slopes, that were flooded for a considerable period every year, had 10YR5/1, whereas those in small, closed depressions, subject to variable and often incomplete flooding, had 2.5Y 4-5/2.

In Morocco (Bryssine, 1967) and Chad (Pias, 1970) it was observed that "Chromic" Vertisols in flooded sites had 2.5Y or 5Y, whereas those in adjoining areas that were subject to less severe flooding had 10YR. Guy D. Smith suggested using the hue in Vertisols as an additional diagnostic property for wet conditions: chromas of more than 2 could be allowed for Pellusterts in soils that have hue of 2.5Y or yellower.

Vertisols on datum sites in the Central Sudan clay plain have hues of either 10YR or 2.5Y. Flooding conditions are the same for both hues, but soils with 2.5Y seem to occur more frequently in areas with higher rainfall.

Factors that govern soil colour in Vertisols

The origin of the colour of Vertisols has been the subject of many studies that mainly concentrated on the dark colour (low value) of soils that had low amounts of organic matter. This low value is now generally attributed to organic matter that, complexed with clay and strongly tied to the clay surfaces, has a strong pigmenting effect. Vertisols with lighter colour (value 3.5 and above), the Entic subgroups in Soil Taxonomy, occur in drier regions.

Chroma and hue of the colour are related to drainage conditions. The montmorillonite in Vertisols is often rich in Fe (Paquet, 1970). In situations that allow some internal drainage part of the montmorillonite is decomposed, ferrous ions are released, and these oxidize to ferric oxide. The type of iron oxide formed has a strong bearing on the soil colour (Schwertmann and Taylor, 1977). Iron oxide formation in soils is dependent on Fe concentration, pH, Eh, and temperature.

Mottling

Mottling in Vertisols usually refers to spots of redder hue and/or higher chroma that are due to accumulations of ferric oxides. These mottles are

sometimes accompanied by "mottles with chroma of 2 or less." Mottles occur either in the surface soil, or in the lower part of the solum and the upper substratum, or in both; some Vertisols have mottles throughout the solum.

In the surface soil, mottles occur as alignments along roots and are restricted to interpedal voids. This type of mottling indicates periodic waterlogging of the surface soil. It is diagnostic, in Soil Taxonomy, if it occurs in the upper 50cm and if it is "distinct or prominent." Unfortunately, field descriptions are not always specific on the contrast of mottles. Another difficulty is that brownish/reddish/yellowish features described as segregations, nodules, and the like, may not have the same genetic implication as mottles have. Mottles are always formed in place. Any hardened ferric segregation, however, may have been moved upwards from lower soil horizons.

Mottling in the surface 50cm occurs more often in "Pellic" than in "Chromic" Vertisols. It is diagnostic on the great group level to define Aquic subgroups of Chromoxererts and Chromuderts. It is not a defined diagnostic property with Chromusterts and with "Pellic" great groups. Mottling is, apparently, considered to be diagnostic for weak hydromorphic conditions, low chroma for more severe waterlogging.

It seems that in some areas mottled Vertisols are more common than in others and there is no apparent relation to overall flooding conditions. In large areas of Chad, for example, both "Chromic" and "Pellic" Vertisols have mottles, whereas in some parts of the Central Sudan clay plain, e.g. the Kenana, no surface soil mottling occurs, not even in low-chroma Vertisols that are subject to extensive flooding. All Vertisols in the Bor and Kongor districts, Upper Nile Province, are Pellusterts (ILACA, 1979, 1981). They cover extensive floodplains and are submerged for a considerable length of time every year. Mottling as rusty alignments along roots is common in the slightly acid surface horizons. Some Pellusterts have a slightly alkaline surface soil and contain calcium carbonate concretions and lack mottling.

The relation with pH is evident from these examples from the Sudan. The Kenana profile is a sodic Pellustert, with ESP between 16 and 37, and pH (H_2O, 1:5) between 9.2 and 9.7. Ponnamperuma et al. (1967) have shown that at pH above 8 the mobile ion Fe^{2+} aq, is practically absent. Concentration of ferrous iron to form mottles upon oxidation to ferrix oxides will, under these conditions, not take place.

Mottles in the lower solum and upper substratum have often been described, both in "Chromic" and in "Pellic" Vertisols (Findlay et al., 1964; Bryssine, 1967). In the Vertisols of the Central clay plain and the Nuba Mountains clay plain, Sudan, such mottling usually consists of fine segregations of ferric and manganese oxides, soft and hard concretions, and coatings on peds. Calcareous concretions occur impregnated and coated, apparently "in situ," by ferric and manganese compounds (Blokhuis et al., 1968/1969). Very often chromas are above 2 and there is no indication of an increase in intensity of these "hydromorphic conditions" with depth.

Some of the Sudan Vertisols with mottled subsoil overlie weathering rock at shallow depth, and the "hydromorphic appearance" may be due to the variegated colour of a saprolite. But it may also be due to pseudogley. Percolating water may stagnate on a rocky substratum or other impervious layer and build a perched water table.

Other morphological indications

A poorly drained Vertisol may differ from a better-drained one in several morphological properties that are induced by the longer wet and the shorter dry period. Several of these properties, alone or in combination, affect soil structure (Blokhuis, 1982) and could, therefore, in principle, be used as morphological criteria for hydromorphic conditions. It is, however, doubtful whether the correlations that have been found are of more than local importance; in most cases they seem to result from a specific combination of environmental factors. Besides, they cannot easily be quantified. A few examples may illustrate this.

When flooding is confined to "slick spots," the high exchangeable sodium present will affect the soil structure. Peds will be larger, intersecting of slickensides less well expressed and a surface crust may replace the mulch. These modifications from the "central concept" of Vertisol structure are due to the greater shear and tensile strength of Na-montmorillonites as compared with Ca-montmorillonites (Warkentin and Yong, 1962; Dowdy and Larson, 1971).

In Chad Audry (1968) and Bocquier et al. (1968), mapped soil associations appear in which drainage was the essential variable factor. Self-mulching Vertisols grade through Vertisols with coarser textured surface soil into either hydromorphic soils or sodic soils. Either or both of the shorter period of disiccation and the increased sodicity could explain the coarser structure of the more poorly drained soils.

WATER MOVEMENT IN VERTISOLS

The subsoil of many Vertisols shows mottles, and the nature and origin of this "hydromorphic appearance" merits discussion: Are these mottles induced by percolating surface water, or are they due to a groundwater table or perched water table? And this brings us to the more general problem of the feasibility of phreatic levels in Vertisols.

Influence of vertical cracks

An important aspect of the water movement in Vertisols is related to the anisotrophic morphology of these soils due to the presence of vertical cracks and oblique macropores between slickensided ped surfaces. Ritchie et al. (1972) found that small-diameter cores gave too low values for the hydraulic conductivity in Vertisols, because the effect of the large cracks appeared underrated. Blake et al. (1973) observed that when water was added at the surface of a Pelool (a Vertisol-like soil in Germany) most of it flowed down along the walls of cracks, bypassing dry or moist soil inside slowly permeable peds. Buoma and Dekker (1978) introduced the term "short-circuiting" for this flow of free water in unsaturated soil. In field experiments conducted in riverine soils in the Netherlands, they showed that while the surface soil remained relatively dry, flow through continuous cracks contributed to wetting of the subsoil and a rise of the groundwater table. Flow of water in such soils cannot be described by using Darcy-type flow theory,

and water tables cannot be observed by unlined boreholes (Bouma et al., 1980).

Vertisols differ from the soils studied by Bouma and co-workers in the length of time that cracks are capable of conducting free water to the subsoil. In strongly self-mulching Vertisols, cracks, at the end of the dry season, are covered up at the surface by fine aggregates. Short-circuiting will be limited, as the surface mulch functions as a light crust (Bouma, 1982). When the cracks are open at the surface, considerable short-circuiting can be expected in the early stage of wetting, but soon the swollen soil will act as a barrier against water entry. At the same time, cracks close, particularly in soil that is being wetted from above. During the (short) period that large cracks are filled with water at atmospheric pressure, a discontinuous perched water table develops. This "water table" is only present at the sites of cracks, and is, therefore, fundamentally different from a water table in sand. In fact, the use of the term "water table" is quite debatable in this case.

In the later stages of wetting there is only unsaturated flow from the wetted surface and from the cracks. The unsaturated flow is, in Vertisols, very slow and not far-reaching (Lewis, 1977), even when there is an unlimited supply of water from the surface (Farbrother, 1972).

Lateral flow

Limited though it may be in most Vertisols, it is feasible that unsaturated flow of water reaches depths well below the cracking zone. This water could generate a groundwater table, or induce the slow rising of an existing one. Talsma and Van der Lelij (1976) found that in irrigated rice fields significant amounts of water bypassed sections of the unsaturated topsoil, and contributed to rising water tables. The soil studied was an Australian swelling clay soil, but no details on its morphology were given. In the Sudan Gezira, such deep penetration of surface water is only known under exceptional circumstances; Farbrother (1972) found that water penetrated to 9 m depth under an unlined irrigation canal that was known to have been full for at least 35 years.

Most observations in the Gezira on "normally" irrigated areas show, however, that moisture contents below 1 m depth are constant at about 20-25%, which equals the moisture held at wilting point. Yaalon and Kalmar (1978) found no deep penetration of water in Israel Vertisols between 2 and 6 m depth.

The possibility that a groundwater table develops in a smectite clay sediment from a lateral supply of water (a phreatic level in connection with a lake or river surface) has to be rejected on the grounds that lateral movement of water in Vertisols is negligible. It is well known that subsurface drainage in Vertisols by ditches or tile drains is practically impossible (Dudal, 1965).

Influence of montmorillonitic clays

Bocquier (1973) considers the absence of a groundwater table a characteristic feature of clay plains in subhumid to semiarid regions that have,

typically, a dominance of montmorillonitic clays. These clayey sediments will act as impermeable screens to both vertical and lateral movement of water, due to the swelling of the clays upon wetting. Only perched water tables can develop or there is merely a surficial wetted soil body. In the Chad basin such clay plains, with Vertisols, cover considerable areas. These plains are inundated in the wet season, subsequently subject to strong desiccation, and there is no building up of a water reserve at some depth. In toposequences described by Bolet (1978) in Upper-Volta, the upper members (Inceptisols, Alfisols) have a groundwater table. This phreatic level emerges at the footslope. The lowest members of the catena, below the footslope, are Vertisols that are subject to surface hydromorphism only.

As a preliminary conclusion, it may be stated that groundwater in Vertisols is undefined by any operational definition, as no hydraulic equilibrium can be reached; "groundwater" in profile descriptions probably refers in most cases to free water flowing in a coarser-textured substratum, and "gleyed subsoil" to a clayey horizon where hydromorphic conditions are the result of capillary water rising from such a waterbearing layer.

However, there are references to groundwater being present in the solum or in a substratum that consists of smectite clays.

Kerkhoven and Jelley (1964) described Vertisols of the Kafue Flats Polder, Zambia. These soils have wide cracks till 90 cm, but are "permanently wet, uncracked and almost totally impermeable" below about 120 cm. This description suggests the presence of an unripened watersaturated mud, probably consisting of montmorillonitic clays.

Filipovski (1974) found that in alluvial plains in Yugoslavia, with heavy montmorillonitic clays, Vertisols (Smolnitzas) occurred next to nonvertic hydromorphic soils. The latter are continuously wetted by groundwater; the former are subject to superficial desiccation sufficient to induce pedoturbation. Filipovski does not make clear in which way both soil types are geographically related, and at what depth and in which kind of soil material phreatic levels are found in the Smolnitzas.

The Smonitzas in the Banat plain of Western Rumania are thought to be of hydromorphic origin. Extensive areas of marshland covered this plain before reclamation began in the 18th century. Smonitzas have formed in a depressed area of the plain with a perfectly level relief. The profile demonstrated on the occasion of the 8th International Congress of Soil Science in 1964 (Guide Book of Excursions, Vol. II, Tour II, profile 16) as a Humic-Gley soil was, in fact, a true Vertisol. It had a groundwater level at 170 cm. There are apparent similarities between this occurrence and that in the Kafue Polder, Zambia.

It is, at first sight, surprising that a Vertisol with deep desiccation cracks overlies a watersaturated substratum at rather shallow depth (120 to 170 cm). But there are similar observations elsewhere, e.g. in nonvertic, but cracking, fine-textured riverine soils in the Netherlands. Bouma and De Laat (1981) found that upward movement of water in these soils was reduced by horizontal cracks that act as barriers. In Vertisols the subhorizontal planar voids that develop between slickensided ped surfaces may have the same function.

CONCLUSIONS

Low chroma (whether defined as 1, 1.5 or less, or 2 or less) is not a reliable indicator of poor or very poor drainage unless it is used in combination with the length of time that waterlogging conditions exist in the surface soil. Slope cannot be estimated accurately enough to indicate the minor variations in topography that determine whether a site is flooded for a longer or shorter time.

Low chroma Vertisols formed "in situ" on hillslopes may have inherited their colour from the parent rock, but an origin due to waterlogging as a result of very slow internal drainage is also feasible.

Hues yellower than 10YR indicate hydromorphic conditions in some cases, but the relationship between hue and drainage is not significant.

Hue and chroma in Vertisols are probably strongly related to the type of iron oxides present and their concentration.

"Distinct or prominent mottling in the surface 50 cm" is a property that indicates waterlogging conditions. However, many severely flooded Vertisols do not show surface mottles; the absence of mottling in such Vertisols is probably caused by the immobility of Fe^{2+} and Mn^{2+} in an environment with high pH.

Mottling in the subsoil or the substratum may indicate the presence of a transient perched water table. It may also result from "in situ" weathering of primary minerals.

Other morphological parameters that could indicate poor drainage, such as soil structure and sodicity, are not (yet) operational; they cannot easily be quantified and seem to be influenced by local factors. These properties could, perhaps, be diagnostic on a low categorical level or be used in soil mapping.

Groundwater tables in Vertisols cannot be defined.

Transient perched water tables in the solum are feasible as a collection of cores of free water at the sites of vertical cracks, standing above an unsaturated subsoil without macroporosity.

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THE WATER/AIR REGIME OF SWELLING/SHRINKING SOILS

E. Schlichting

It is generally known that Vertisols (cf. Dudal, 1965) and Pelosols (cf. Schlichting, 1968) are characterized not only by certain mineral materials (with a high clay content and CEC, which often are lithogenic), but also by a typical pedogenic variation of their structure in space and time. Despite this, these soils are frequently characterized by features of their material instead of their structure and in the latter case, by methods which are adequate for rigid matrices only. It shall be shown in this paper that the results of such analyses do not contribute sufficiently to the understanding of these soils having an elastic matrix, and often even are misleading. If not stated otherwise, the figures are taken from the dissertation of D. Gaese (1979). She investigated ± pseudogleyed (Pg) Pelosols (Pe), corresponding with aquic Haplumbrepts to Eutrochrepts, from Keuper (km_1) or Dogger (b_α) ± marly clays (MeT) on plateaus or slopes under spruce (F_1) or beech (Bu). For three typical profiles humus and clay contents, apparent density and pore size distribution of the swollen horizons (PWP = permanent wilting point, tension > 15 bar, aWC = available water capacity, 15-0.33 bar, AC = air capacity, <0.33 bar; all as % v/v) are shown in Fig. 1a (taken from Gaese and Schlichting, 1975).

CONSEQUENCES OF CHANGES IN PORE VOLUME AND PORE SIZE DISTRIBUTION

From Fig. 1b it can be derived that a decrease in the amount of water (WV, here as l/m^2, from neutron probe measurements) in the solum is followed by a decrease of the pore space (PV, here as l/m^2, calculated with specific weights and apparent densities from γ-probe measurements) and vice versa (thus causing a "breathing" of such soils with an oscillation of their surface of about 6-8 cm). Expectedly the amplitude is larger under beech than under spruce and a time lag during the growth season is more pronounced. The latter is valid also for the shallower soils 1 and 2, due to the slower reaction of the denser C_{V1}-horizons to changes of evapotranspiration: precipitation. This can be derived from the primary data (not shown here), and also that, in the average of the year, the pore volumes of the horizons are lower than those determined in the laboratory.

Thus, the air volumes (AV, as % v/v) calculated in the usual way, i.e. from PV-WV (both as % v/v), taking the same PV data as measured once with wet(ted) samples (see Fig. 2c). This means an overrating of the air volume in such (sub)soils by the conventional method.

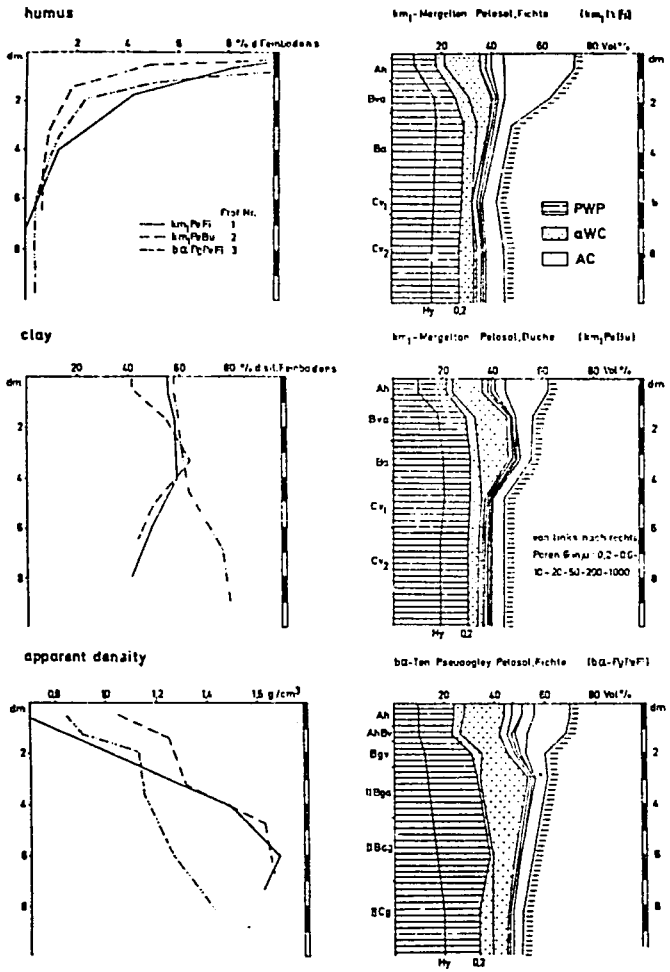
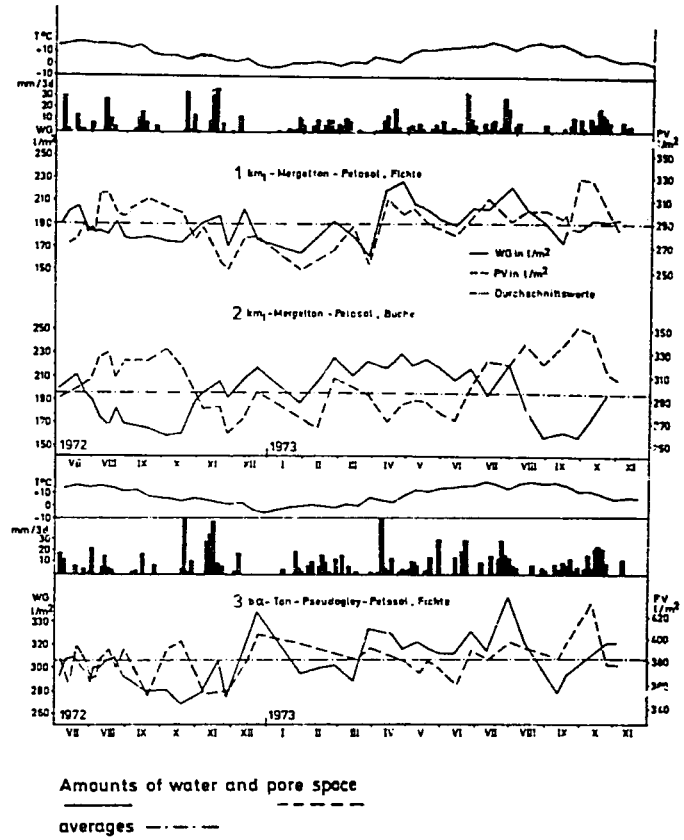


Fig. 1a Material and structure of three Pelosols



b Amounts of water and pore space as function of time

When and where the pore volume decreases less, more cracks are formed. This change in the pore size distribution, however, does not only increase the share of coarse pores but, according to measurements of Schweikle (1982) with a Hg porosimeter, that of the fine pores as well (see Fig. 3), both at the expense of medium pores. This means an increase of the PWP and, thus, an overrating of the available water volume (aWV) calculated from WV-PWP, probably mainly in the topsoil.

These data show that in such soils AV or the air capacity (AC) cannot be estimated by subtracting WV or the water capacity (WC) from PV, and aWV or aWC not by subtracting the PWP from WV or WC assuming that in the equations

$$PV = AV+aWV+PWP \text{ and } PV = AC+aWC+PWP$$

for a given soil horizon only the actual values for AV and aWV are changing, the others being the same as measured once with wet(ted) samples. Porosity and pore size distribution of the horizons rather depend on their position in the profile and the weather as well.

EFFECTS OF DRYNESS AND HEAVY RAINS

The drier these soils, the more coarse interaggregate pores are formed in the topsoil and the deeper and wider the cracks extend into the subsoil, thus causing a good aeration in the former and a deep one in the latter (Stirk, 1954). This leads at first to a streaky aeration mosaic. With increasing formation of cracks, their walls act as additional evaporation surfaces (Adams and Hanks, 1964), and these soils may desiccate even at depths much more than such a coarser primary pore system ("cracking drought").[1] On the other hand, cracking may decrease a runoff and increase the infiltration (Johnson and Hill, 1944).

When heavy rain falls with an intensity exceeding the infiltration rate of the aggregates, part of the water moves more or less in the interaggregate pores, thus causing at first a streaky moistening mosaic leading to a sharp decrease of tensiometer readings, followed by a slow increase and again by a sharp increase after every heavy rain, like a fever curve with gradually decreasing maxima (Gaese et al., 1976). This can also be seen in Fig. 4, where the tensions as derived from suction curves and actual water contents or as measured directly are shown. The nonequilibrium means that under these conditions plants can absorb more water (and get less air) than is to be derived from WV-PWP (PV-WV).

The water can also move downwards much faster in the interaggregate than in the intraaggregate pores, leading to a by-pass (Blake et al., 1973). This can already be seen in Fig. 4, but can be demonstrated more clearly with the HTO distribution in the soil after irrigation with 50 mm of tagged

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[1] This possibly explains the deeper weathering of sulphides than of carbonates in these profiles.

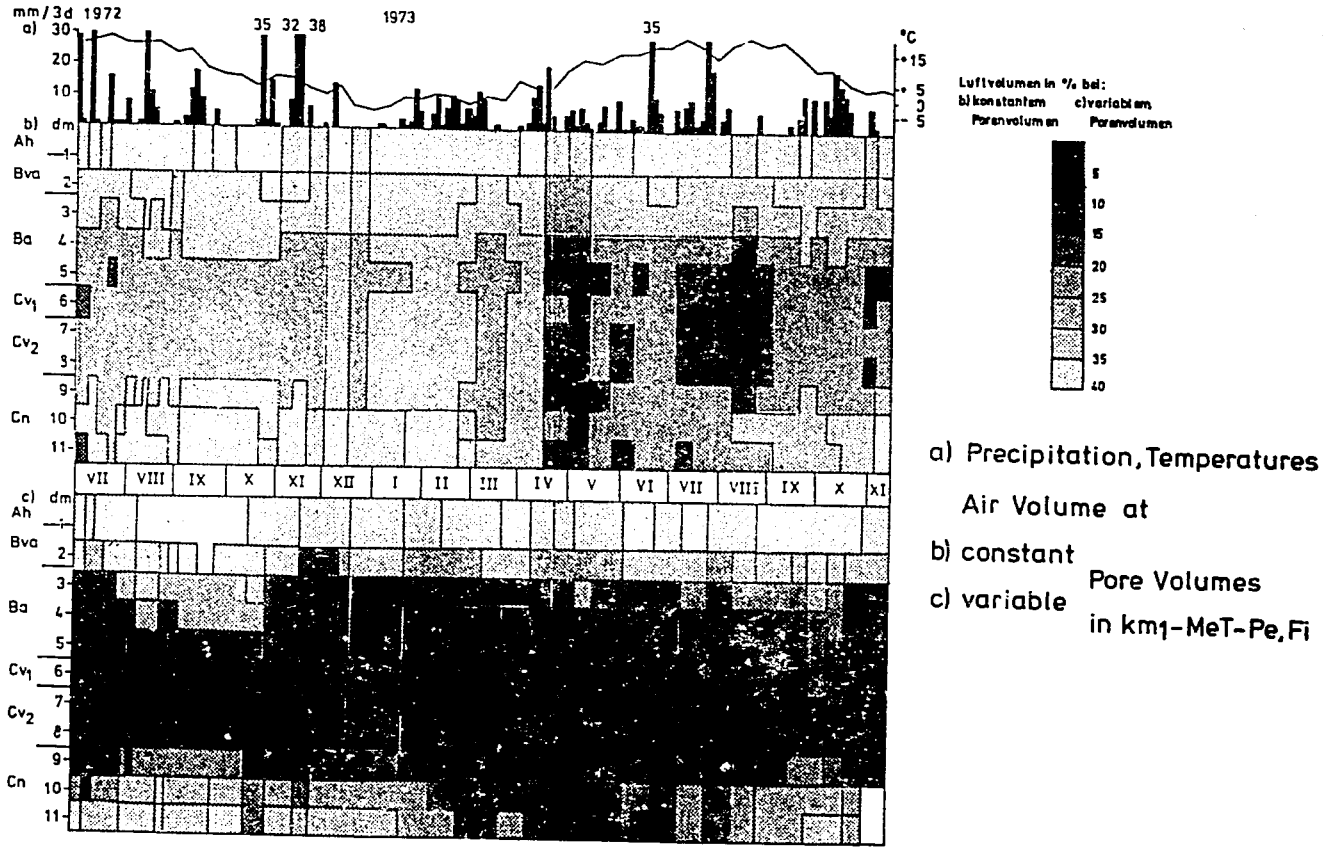
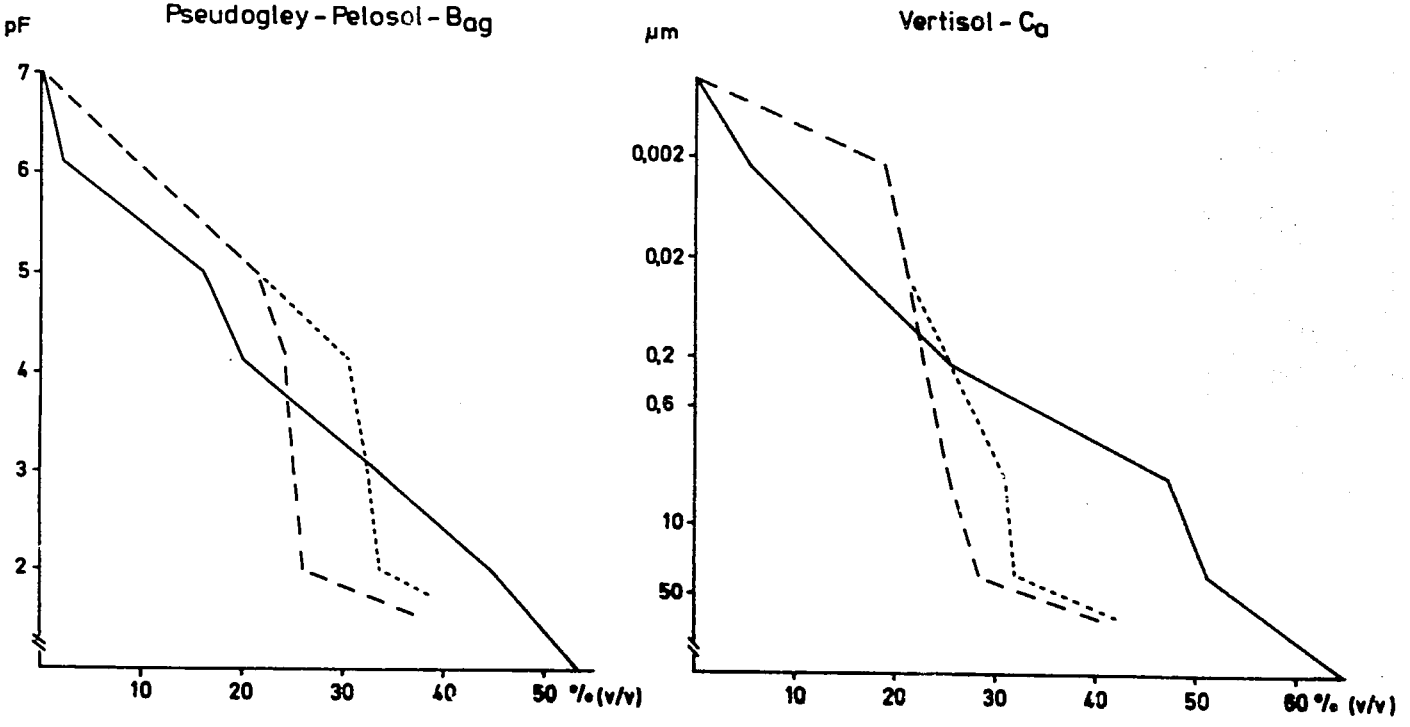
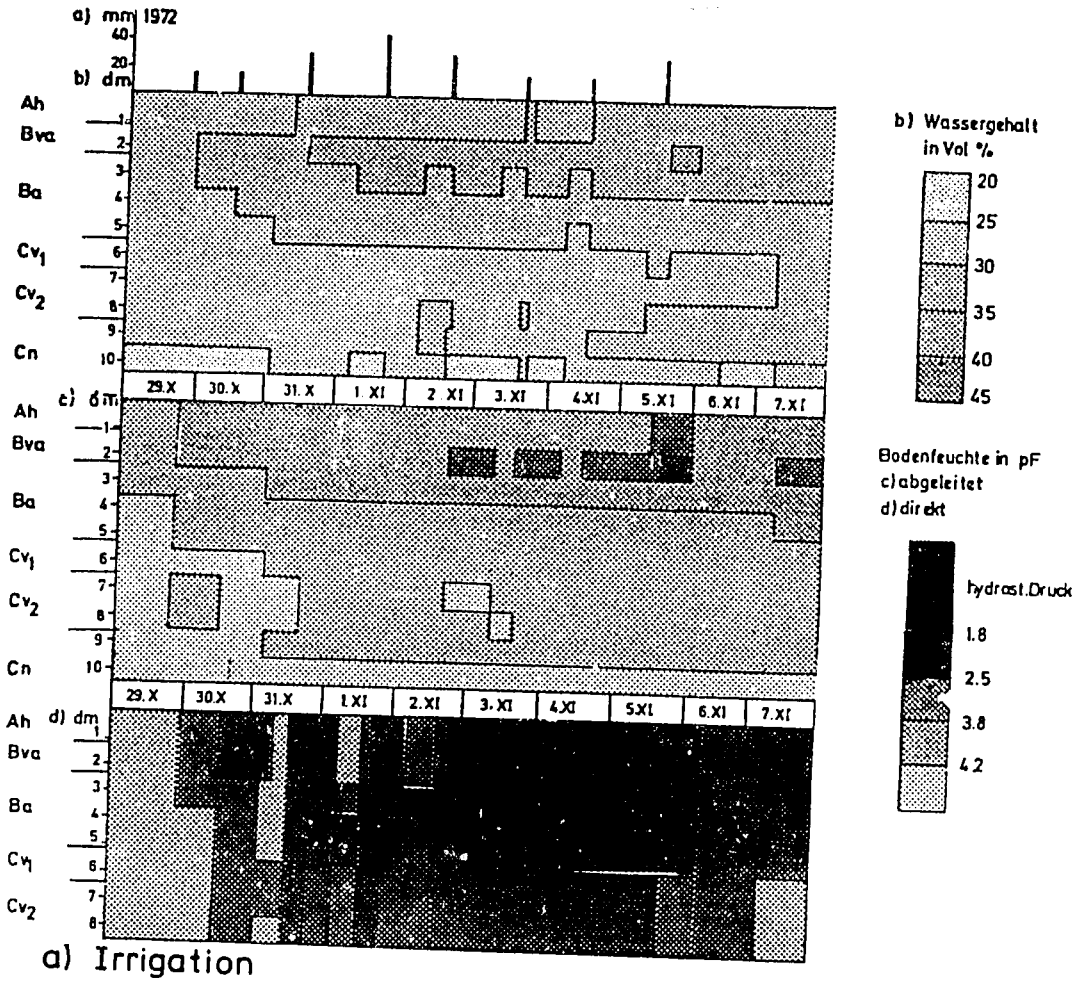


Fig. 2 Air volumes (% v/v) as a function of depth and time

Fig.3 Soil moisture tensions or pore sizes in soils swollen (—) and desiccated to pF 4.2 (---) or 6.1 (– –)
(according to measurements by Schweikle)





a) Irrigation

b) Water Volumes and

c) derived

d) measured Tensions in km1-MeT-Pe, Fi

Fig.4 Tensions (pF) as a function of depth and time after irrigation

water, shown in Fig. 5. After less than 24 hr more than one-third of the water reached a depth below 60 cm. This means that rain which under conditions of layered infiltration would have been held mostly in the upper 20 cm can substantially contribute to the leaching of solutes from the surface.

Such peculiarities are to be expected more the higher the COLE values of the soil are and the less evenly the rain is distributed. To demonstrate this, for a Vertisol from Morocco investigated by Bryssine (1966), the plant-available water (WV-PWP) was calculated assuming that the soil had always the same pore size distribution as the swollen samples (Fig. 6, upper part), and the seepage water (WV-WC, here only data for pF 2.7 available) assuming the soil had the shrunken structure during the whole time (Fig. 6, lower part). It can be seen that in the former case the plants would have been supplied with water only during short periods (whereas actually they were provided sufficiently for considerable yields) and that in the latter a seepage would have occurred during an even longer period (of the bypass type in the beginning of the wetting cycles).

Only continued rain will wet the soil homogeneously (some heavy showers first from the bottom up and then, or after many light showers, from the surface down) and thus create the swollen condition. Then the aeration is very poor even at WV=WC ("adhesion stickiness"). But in well-aggregated B_a-horizons this scarcely ever will be the case (cf. Blokhuis, 1982).

CONCLUSIONS

Pore volumes and pore size distribution or suction curves and air or water conductivity data as determined normally with swollen soils represent just one boundary for the water/air regime of swelling/shrinking soils; the other is the corresponding set of data for the shrunken state. Since the actual conditions depend on the course of precipitation:evapotranspiration rather than the static concept of air and water capacity and permanent wilting point, a dynamic approach with the aid of computer models is needed for a prognosis. This is not only of theoretical interest but has practical implications as well (e.g. increase of water reserves by accentuation or prevention of cracking, irrigation more frequently with small or less with high doses?).

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Fig.5 Yield of Tritium (% of supply)

at different times after irrigation of km_1-MeT-Pe,Fi

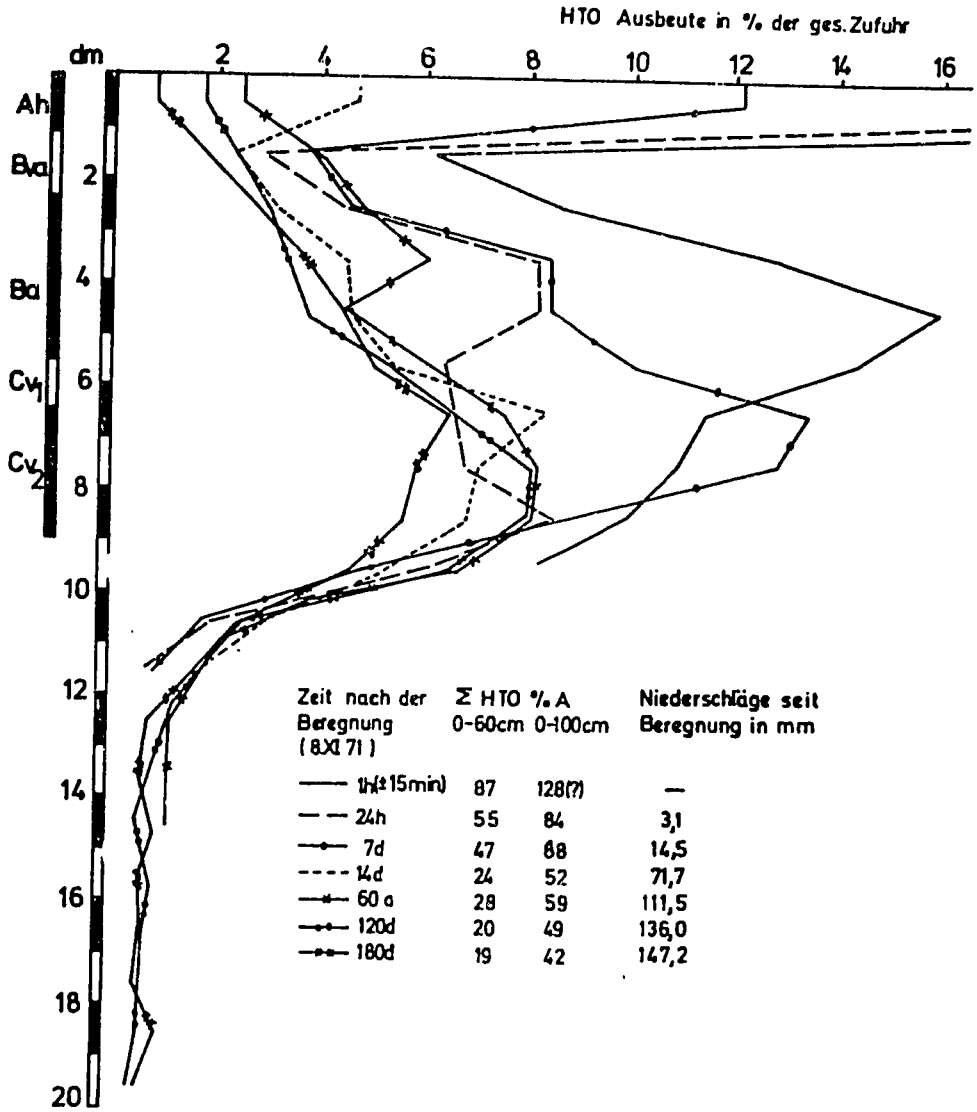
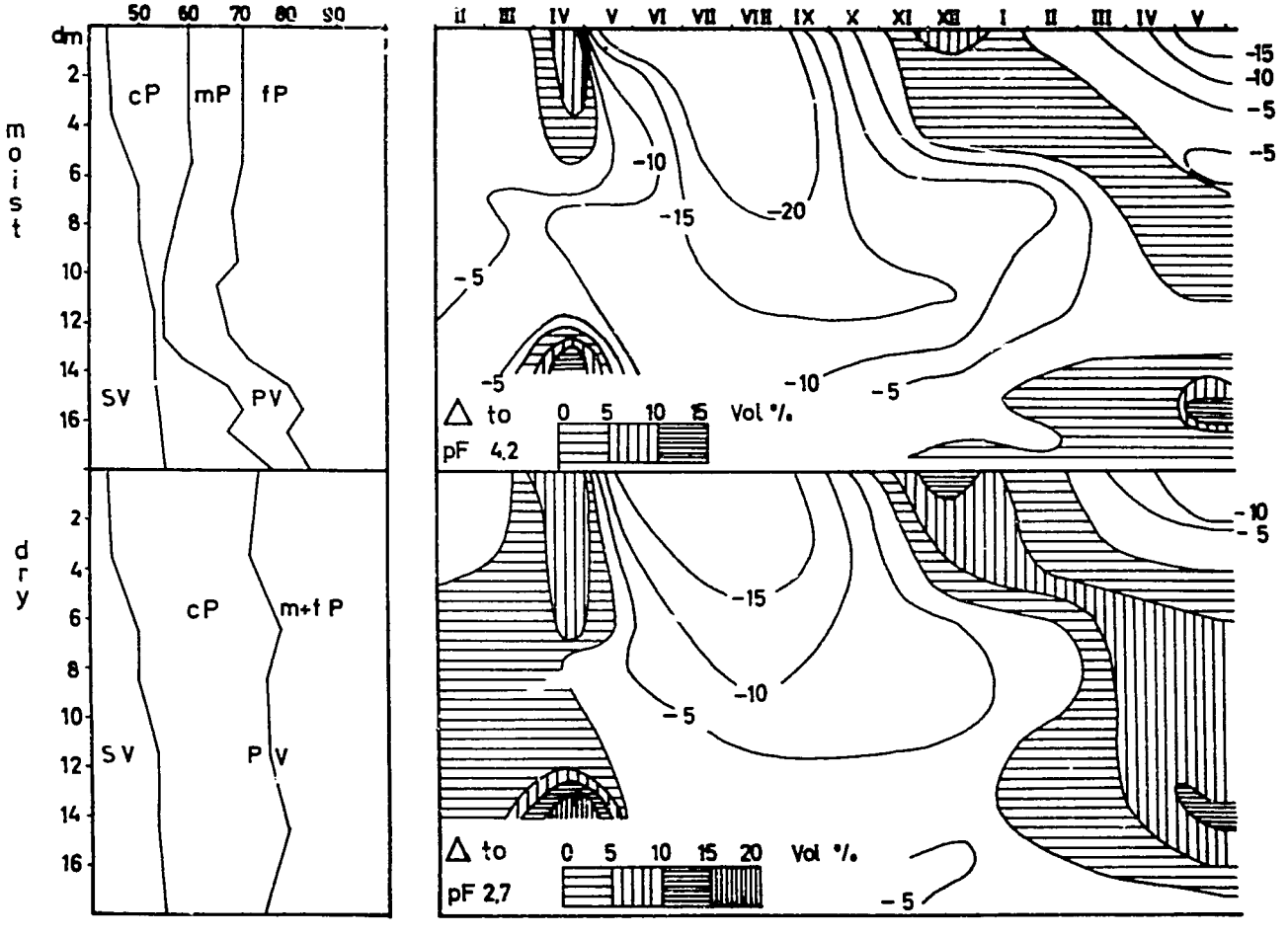


Fig. 6 Porosity and mobile water in a Vertisol (Bryssine)



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ASSESSMENT OF SOIL SALINITY AND ALKALINITY

I. Szabolcs

Roughly one-tenth of the continents is covered by saline and alkaline soils. Their distribution is uneven; in some regions they occur seldom or not at all, while in other regions they are very common, sometimes dominant.

When speaking of the distribution of saline and alkaline soils in different areas we have to look at those geochemical features of the landscape which influence the development of salt-affected soils.

SALT ACCUMULATION IN DIFFERENT LANDSCAPES

It is known that arid and semi-arid conditions contribute to salt accumulation in soils and waters. As a result, the formation of salt-affected soils in desert and semi-desert regions is quite a common phenomenon. The accumulation of electrolytes in soils is, however, a complex process which cannot be interpreted as a simple consequence of climatic effects. The hydrology as well as hydrogeology and geomorphology of a given area have substantial influence on salt migration in waters and grounds. The integrated effects of environmental factors determine the trend of salt migration and the balance of soluble products accumulating in soil layers.

Based on the landscape geochemistry studies of Kovda (1946-1947), Polinov (1956), and Szabolcs (1981), the following landscape types can be distinguished as geochemical regions of salt accumulation in soils.

Table 1. Scheme of landscape geochemistry of salt-affected soils.

Landscape	Main Chemical Type of Salt Accumulation	Dominant Type of Salt-Affected Soils
Salt dome	$NaCl$	Solonchak
Maritime	$NaCl$	Solonchak
Deluvial	Na_2SO_4, $NaHCO_3$	Solonchak, Solonetz
River deltas	$NaCl$, Na_2SO_4, $NaHCO_3$, Na_2CO_3	Solonchak

Table 1. (continued)

Landscape	Main Chemical Type of Salt Accumulation	Dominant Type of Salt-Affected Soils
Dry deltas	$NaCl$, Na_2SO_4	Solonchak, Solonetz
Alluvial plains	Na_2SO_4, $NaCl$ $NaHCO_3$, Na_2CO_3	Solonchak, Solonetz
River terraces	$NaHCO_3$, Na_2CO_3, Na_2SO_4, $NaCl$	Solonchak
Salt lakes and marshes or swamps	$NaCl$, Na_2SO_4, Na_2CO_3	Solonchak

As can be seen in Table 1, different landscape types are associated with different chemical and pedological types of salt accumulation as well as with different soil types. In several landscape types the climatic conditions have substantial influence on the chemistry and magnitude of salinity and alkalinity. In alluvial plains, for instance, Na_2SO_4 and $NaCl$ accumulate in arid regions, resulting in Solonchak soils, while in more humid areas Na_2CO_3 - $NaHCO_3$ accumulation prevails, associated with Solonetz soils.

Saline and alkaline soils develop in different climatical as well as geochemical regions, influencing the genetics and properties of many soil types. In the legend of the Soil Map of the World and in Soil Taxonomy the term "Saline phase" or "Sodic phase" indicate the occurrence of salt accumulation in different soils. If, due to natural or antropogen factors in soil formation, the accumulation of salts is progressive from the given soil in saline phase or alkaline phase, Solonchak or Solonetz may develop.

INFLUENCE OF SALINITY AND ALKALINITY ON DIFFERENT SOILS

As is clear from the foregoing, salt accumulation in soils is always associated with certain environmental conditions. Given the climatical, hydrological and geomorphological properties of the landscape, the soil material, whose composition and pattern we express as type, or in other taxonometrical terms in our classification systems, is primarily exposed to the influence of increasing or decreasing salt concentration in the soil solution. As a result of interaction of salts with soil material, different kinds of salt-affected soils develop. For example, it is well known that in the environment of arid soils Solonchaks are frequent and no Solonetz can be found in deserts and semi-deserts. On the other hand, in alluvial plains and river terraces of the moderate climate areas Solonetz is the prevalent type of salt-affected soils.

Regarding the chemistry of soil salinization and alkalinization, two main factors determine the dominant chemical type of salts: climate and landscape geochemistry. These factors determine whether NaCl, Na_2SO_4, Na_2CO_3, or $CaSO_4$, $MgCl_2$, $MgSO_4$ will prevail in the processes of salt accumulation.

The parent material as well as other factors of soil formation influence the interaction between salts and soils. To a great extent they determine which pedological type will be the result of such interactions. To mention just one example, Solonetz soil will never form in coarse sands because the development of this type demands a certain amount of highly dispersed soil material.

If we want to understand the regularities of salinization and/or alkalinization of a given soil region, especially if our aim is to mitigate or to arrest the processes affecting production, it is necessary to study the peculiarities of the soil types affected by the accumulation of electrolytes.

SOME ASPECTS OF SALINITY AND ALKALINITY IN VERTISOLS

Vertisols are widely distributed in different climate regions. Some of their properties are similar to those of the Solonetz soils: high clay content, cracking, high water retention, etc. In some places it is difficult even to make a clear distinction between Solonetz and Vertisol on the basis of a superficial land survey.

In many cases, Vertisols are affected by salinization and/or alkalinization. This process is well known in general; still there are many uncertainties and shortcomings where the influence of electrolytes on Vertisols is concerned.

When the accumulation of salts, mainly of NaCl and Na_2SO_4, is very intensive and the concentration of them in the top soil horizons exceeds certain threshold limits, Solonchak or saline soils will develop. In such cases, practically independently from the type of the original soil material, the effects of the high salt concentration will determine not only the pedological pattern, but also the chemical properties, as well as the agronomical value of the soil.

The picture is not so clear when the concentration of electrolytes which have effects on the Vertisol is comparatively low. In such cases the sodium ions react to the soil clay material, which is always abundant in Vertisols. In spite of the large number of papers and books describing the rate and character of ion exchange processes in soils, we still lack an exhaustive study of the characteristics of many practical consequences of this phenomenon, which are somewhat different in different soils (Richards, 1954).

Adverse effects will develop in the soil in proportion to the percentage of these exchangeable sodium ions (ESP). It is generally accepted that ESP values of over 15 result in the formation of columnar B horizon in soils, is associated with the degradation of soil fertility, the decline of water-physical properties and growing sensitivity to drought. However, it was observed in many countries that the negative effects of exchangeable sodium

ions sometimes also appeared when the ESP value was lower than 15, while in other cases, in spite of values of 20-25 or even higher, ESP soil fertility remained acceptable. In all probability under different soil conditions, when the soil type, the mineralogical composition, organic material, etc. are diverse, the threshold values of ESP should be less generalized for all soils, but more associated to the given soil conditions. Further studies in this direction are important not only theoretically, but also with the proper evaluation of salt-affected Vertisols and other soils in view so that methods can be elaborated for their utilization and amelioration if possible.

As long as the results of basic studies on the impact of salinity and particularly of alkalinity on different soils are not available, local experience should be the guideline to estimate the ESP values for the purpose of pedological as well as practical conclusions.

In close relation to the effect of ESP in Vertisols, the chemical type of sodium salts and their influence on soil properties should also be studied more in the future.

Most of the available technical literature, particularly the papers discussing irrigation, deal with the problems of salinity induced by NaCl and and Na_2SO_4. However, in many places, and often in Vertisols, the sodium ions capable of alkaline hydrolysis prevail. The alkali medium, which often occurs in Vertisols, benefits the dominant actions of sodium ions. In such cases even low sodium concentration may affect soil colloids very intensively, and have a detrimental effect on soil properties and fertility.

Figures 1 and 2 illustrate the specific effects of different sodium salt solutions conducted on a Vertisol from the Hungarian Plain (Szabolcs, 1969).

The experiments were carried out in soil columns treated with different soil solutions (concentration: 0.1 N). After the treatments, we measured the water permeability of the soil column.

The data in Figure 1 show clearly that, while the solutions of NaCl and Na_2SO_4 decreased the permeability of soils only moderately, the Na_2CO_3 solution made them practically impermeable.

In Figure 2 the effect of different sodium salt solutions on soil aggregation is demonstrated. We measured the Vageler-factor in different layers from 0-70-80 cm, in untreated soil as well as in soils treated with NaCl, Na_2SO_4 and Na_2CO_3 respectively.

The Vageler-factor = $C = \frac{/a-b/100}{b}$ where:

a = the amount of the irreversible microaggregates on basis of the mechanical analysis

b = the amount of the irreversible microaggregates on basis of the microaggregate analysis.

The results of the experiment shown in Figure 2 demonstrate that the destruction of soil aggregates was more intensively affected by $NaCO_3$ than by Na_2SO_4 or NaCl.

Figure 1. Water permeability of soils treated with different salt solutions.

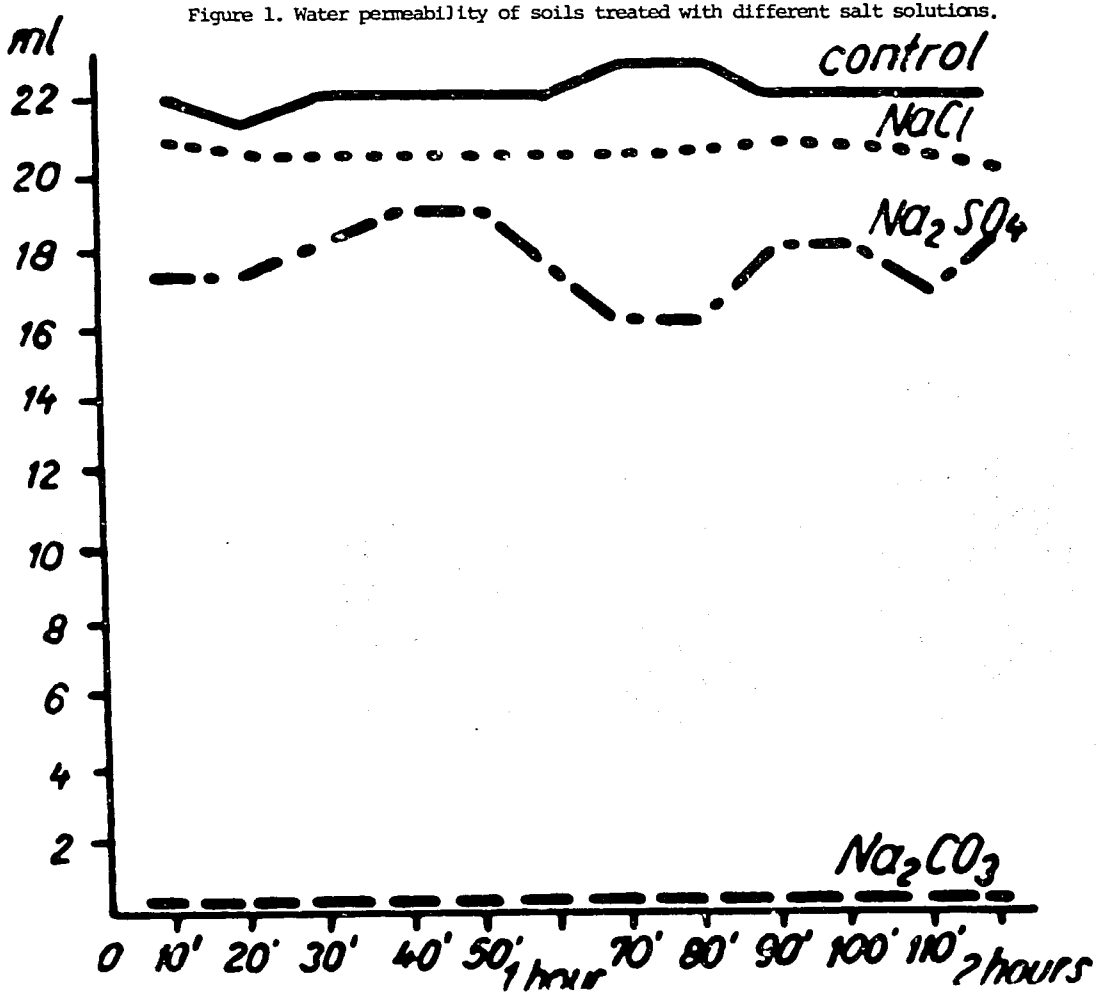
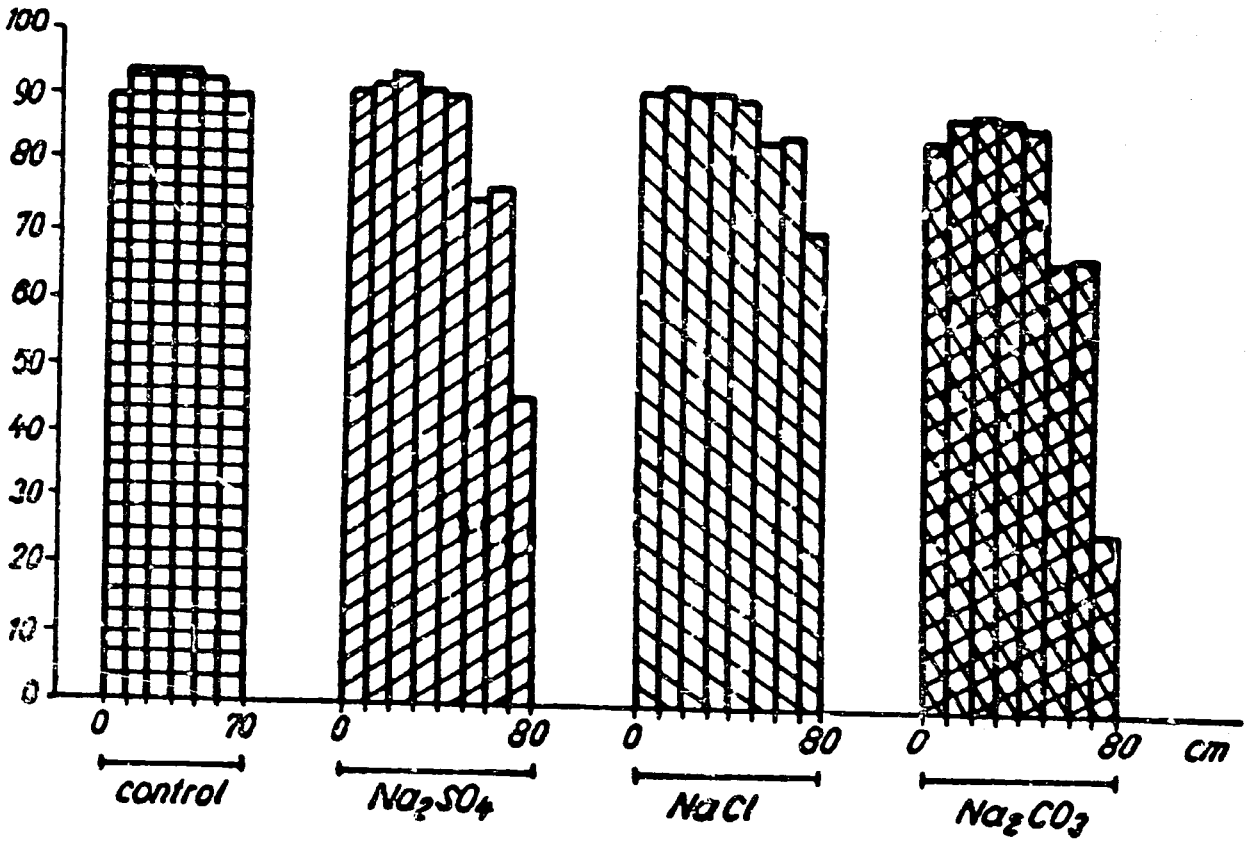


Figure 2. The structure factor of Vageler in the soils treated with different salt solutions.



ENVIRONMENTAL CONDITIONS

When assessing soil salinity and/or alkalinity, environmental conditions must be always taken into consideration. As salinity and alkalinity occur in different climatical, hydrological, and geological conditions, there are no uniform methods for the fight against those adverse processes. Also the economical conditions of a given area as well as the patterns of farming influence substantially the strategies to be elaborated for dealing with salinity and alkalinity.

Rainfed agriculture

Rainfed agricultural production in salt-affected soils is possible mainly in nonarid conditions. In river valleys and alluvial plains salinity and alkalinity often occur in semi-humid, but also in humid regions. If the annual precipitation is not sufficient for the removal of excess salts from the soil profile, drainage and in some cases supplementary irrigation should be applied in order to gain yield on salt-affected soils. Under moderate climatic conditions the yearly distribution of precipitation is often good and sufficient for keeping the salt balance in soil in such a quasi-equilibrium that the plants can tolerate the salinity and/or alkalinity (International Source Book, 1967).

Where the salt concentration of soils is comparatively low and the main problem is alkalinity resulting in poor water-physical conditions, mainly the Solonetz soil types occur. For the reclamation of alkaline soils the application of chemical amendments is a well known and widely employed method. In nonarid conditions the application of gypsum and other acid products is sometimes effective even without irrigation. Due to the low degree of salinity in many cases even moderate doses of gypsum result in the improvement of soils.

Particularly in the last decades the by-products of industry, like phosphorgypsum, different H_2SO_4 products, iron sulphate, sulphur, etc., have gained popularity in their application, partly due to their availability and cheap price.

In some Solonetz soils in the U.S.A., Canada, Hungary, Argentina, etc., where the horizon A of the soil is slightly acidic, the application of $CaCo_3$ and industrial by-products containing such substances is usual.

Irrigation

In irrigated areas, the problem of salinity and alkalinity has been well known for many thousands of years. The decay of many ancient civilizations was associated with the so-called secondary salinization and alkalinization of irrigated soils.

Under arid and semi-arid conditions, irrigation in most cases provokes salinization. It is only in soils which have good natural drainage that irrigation does not result in salt accumulation.

Before constructing irrigation systems in arid conditions, a special survey of soils, hydrological, geological and other environmental conditions should be conducted in order to predict the consequences of irrigation. Potential salinization due to irrigation should be predicted and if the hazard is considerable, the spots to be irrigated should be selected where the possibility of adverse processes is less or where they can be controlled.

Table 2. Scheme of recommended methods for the control of salinity and alkalinity in irrigated areas.

Before construction of irrigation system:

Preliminary Survey

Landscape	Planned Irrigation
climate	available irrigation
hydrology	water - quantity and quality
hydrogeology	groundwater - depth and quality
geomorphology	technology of irrigation cropping patt rn
soils	tolerance

During Irrigation:

Monitoring

salinity and alkalinity of soils
ground water table
chemical comp. of groundwater
chemical comp. of irrigation water
filtration
physical soil properties
possible toxic elements in soil and water - B, etc.

Table 2 shows that the prediction of secondary salinization and alkalinization of soils to be irrigated should be based on a preliminary survey of the landscape and soils before the construction of irrigation systems. This way it is possible to take the necessary steps for preventing these adverse processes.

During the irrigation, a well-organized monitoring of soil and water properties is necessary in order to notice the changes, if any, and to make precautions if necessary. The methods for monitoring, the timing, and places of sampling depend on local conditions.

SUMMARY

Soil salinity and alkalinity may develop in different areas and associate with many soil-forming processes. Depending on soil types and local environmental conditions, salinity and alkalinity influence the soil and the landscape diversely.

Arid conditions contribute to salinization, but particularly alkalinization; these also occur in semi-arid and semi-humid areas.

The threshold values of ESP causing poor water-physical properties in soils have not been exactly elaborated. In many cases, e.g. in Vertisols, anomalies have been observed in application of 15-20 ESP values as characteristics for Solonetz soils. Research aiming at a more precise understanding of the interaction of cations with soil colloids should be done, giving more consideration to the different soil types.

The management of salinity and alkalinity of soils is different in rainfed and in irrigated conditions. Secondary salinization and alkalinization are old but growing hazards in most irrigated areas. Preventive means and permanent monitoring are necessary to control these processes.

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USTOLLIC, XEROLLIC, AND BOROLLIC SUBGROUPS OF ARIDISOLS

K.W. Flach, W.D. Nettleton, and J.D. Nichols

The impact of recognizing ustollic, xerollic, and borollic subgroups of Aridisols (designated "mollic subgroups" for ease of discussion) on the complexity of Soil Taxonomy, the adequacy of the current definition and justification for mollic subgroup in terms of soil genesis and soil interpretations are examined.

It was found that the use of sand/clay ratios in the definition of mollic subgroups can lead to absurd results and to unsatisfactory groupings.

At this time, the distinction between ustollic and xerollic subgroups has not been quantitatively defined. In the U.S., this distinction can be made relatively easily because of fortuitous geographic relationships, but such conditions may not exist in other parts of the world.

The usefulness of mollic subgroups in improving the structure of the order Aridisols was examined on the basis of the number of soil series in various taxa in the United States. Abolishing mollic subgroups would reduce the number of subgroups in the order Aridisols from 94 to 55 and would cause an undesirable increase in the number of soil series in only three families.

Currently, in the U.S., we recognize only one soil series in more than half of the 650 families in Aridisols; in only 10% (64) of the families, more than four soil series are recognized.

The genetic significance and practical usefulness of mollic subgroups and the significance of current diagnostic criteria was evaluated on the basis of three studies. These studies related organic matter content to range productivity, climate, and clay content. In one of these studies, it was found that organic matter content is highly correlated with clay content and not with climatic parameters. In the other two studies organic matter content was highly correlated with mean annual precipitation and range production but not with clay content or sand/clay ratios. An attempt was made to reconcile these conflicting conclusions. It was concluded that the recognition of mollic subgroups is of genetic and practical usefulness and that organic matter content can be used as a diagnostic criterion with amount of vegetation serving as field evidence in mapping. Clay content may be useful as a diagnostic criterion to keep associated soils in parallel subgroups but the available data were inadequate to develop a firm recommendation. Establishing different critical values for sandy, loamy, and clayey soils may be more satisfactory than the present criteria. No strong evidence for maintaining the distinction between xerollic and ustollic subgroups is available now but range scientists would recognize differences in the composition of plant committees for the two subgroups.

THE HYPERCALCIC HORIZON

R. Tavernier and M. Ilaiwi

Pedogenic accumulation of carbonates in soils occurs when sources of carbonates are present and when soil moisture conditions are conducive to their accretion. In fact, large areas in the world (particularly in arid and semi-arid regions) are covered by soils having horizons of lime accumulation. The accumulation may take place over extended periods of time with often recent additions of carbonates superimposed over previous ones.

It is not always easy to distinguish between carbonates that constitute a part of the sediment (the so-called "primary carbonates") and those which have accumulated in a soil horizon as a result of pedogenic processes, such as dissolution, translocation, and precipitation (the so-called "pedogenic" or "secondary lime"). Pedogenic lime is usually recognized in the soil profile as coatings or laminar pendants on pebbles, as concretions or as soft powdery forms.

Horizons with pedogenic accumulation of carbonates have a wide range of characteristics. Soil Taxonomy presently recognizes two diagnostic horizons of accumulation of calcium carbonate or of calcium and magnesium carbonate: the calcic and the petrocalcic horizon.

In the calcic horizon the percentage of $CaCO_3$ equivalent may vary from a minimum of 5% (in sandy soils) to a theoretical maximum of 100%. The difference between a calcic and a petrocalcic horizon is not based on the amount of carbonates but on the presence of a continuous, strongly cemented hard layer which is a barrier to roots. Although soils with a petrocalcic horizon usually have a high carbonate percentage, a great many soils with only a calcic horizon may have as high or even higher contents of carbonates.

The calcic horizon is used as a criterion to classify the soils in various categories of the system to separate taxa (generally great groups, sometimes subgroups) without considering the great differences in the content of carbonates that may occur. Thus, pedons dominated by carbonates are grouped together with pedons where carbonates constitute only a minor part of the soil and this in spite of the fact that the soil potentialities strongly differ. In the present text of Soil Taxonomy the only possible way to make a distinction between these soils is at the family level, namely as a carbonatic mineralogy class. The family category, however, is too low a level to distinguish genetic horizons, as it mainly deals with materials which are not necessarily the result of a pedogenic process.

Soils characterized by a calcic horizon with a high carbonate content, but without the indurated petrocalcic horizon, have a wide extension in arid and semi-arid regions. They occur generally on soils older than the Holocene and are often associated on the same geomorphic surface with soils having

a petrocalcic horizon. On the other hand, soils with a weakly expressed calcic horizon are generally situated on younger geomorphic surfaces (terraces or pediments).

For those reasons (degree of development and age), it seems desirable to split the present calcic horizon of Soil Taxonomy into two individual diagnostic horizons, namely a (weak) calcic horizon and a prominent calcic horizon. The latter could be named the "hypercalcic" horizon. As early as September, 1969, at a meeting in Ghent attended by Dr. Guy D. Smith, a tentative definition of the "hypercalcic horizon" was prepared and the proposal was made that the calcic horizon limit of 15% carbonate be dropped to 10%. It was suggested that the hypercalcic horizon would be diagnostic at the great group level instead of the petrocalcic horizon. It was also suggested that the hypercalcic horizon would be substituted for the petrocalcic horizon in the definition of Pale- great groups (and the petrocalcic horizon reduced for use at the subgroup or even at the family level). This proposal was discussed at a subsequent meeting of the principal correlators in the U.S. in 1969, but no decision was taken beyond "the decision to study the impact of this suggestion on the classification on the soils of the U.S." (letter of Dr. Guy D. Smith of 18/11/1969).

One may notice that the Desert Project implicitly recognizes the concept of the hypercalcic horizon as the stage III in the morphogenetic sequences of carbonate accumulation, characterized by the continuity of the fabric high in authigenic carbonates.

Since 1969, a great many (and sometimes very detailed) studies have been made of horizons which would qualify for a "hypercalcic" horizon, not only in the U.S. but also in other countries such as Morocco (A. Ruellan, H. Ghanem), Algeria (T. Boyadjiev, N. Belouam, B. Dekkiche), Tunesia (Cocque), Lebanon (A. Osman), Syria (M. Ilaiwi), etc. This horizon corresponds roughly to the horizon of "encroûtement calcaire" in "Sols à profil calcaire fortement différencié sans croûte calcaire indrée" of Ruellan.

The Fifth International Soil Classification Workshop may resume the discussion on the adoption of a "hypercalcic horizon" which is characteristic of large extensions in arid and semi-arid regions. In order to facilitate the discussion, a tentative definition is given below.

> "The hypercalcic horizon is a horizon of accumulation of calcium carbonate or of calcium and magnesium carbonate which is 15 cm or more thick, has a carbonate equivalent of 50 percent or more in the fine earth fraction or 60 percent or more in the fraction finer than 20 mm and contains more than 50 percent by volume of identifiable pedogenic carbonates such as pendants on pebbles, nodules, concretions, clusters, plates or soft powdery forms."

If such a definition were accepted, it might be useful to consider the petrocalcic horizon as an indurated phase of the hypercalcic horizon and the definition of the hypercalcic should also include the present definition of the petrocalcic horizon.

If the hypercalcic horizon is recognized as a diagnostic property, one should also decide at which level it should be used in the classification. In Soil Taxonomy calcic and petrocalcic horizons are (except in the Inceptisols) diagnostic at great group level, either as Calci- or as Pale- great groups. Soils having an argillic horizon are classified into the Pale- great groups on the basis of specific properties of the argillic horizon or due to the presence of a petrocalcic horizon. In soils without an argillic horizon, only the presence of a petrocalcic horizon is required for the Pale- great groups.

Taking the suborder of the Orthids as an example, one notices that Soil Taxonomy provides for a great group of Calciorthids (for Orthids having a calcic horizon) and a great group of Paleorthids (for Orthids having a petrocalcic horizon). The hypercalcic horizon could be used as a diagnostic property at great group level and thus the Orthids would have three great groups characterized by the presence of a horizon of accumulation of carbonate, namely: Calciorthid (with a calcic horizon), Hypercalciorthids (with a hypercalcic horizon), and Paleorthids (with a petrocalcic horizon). It would also be possible to use a hypercalcic horizon as a diagnostic criterion at subgroup level, either in the Calciorthids or in the Paleorthids. The latter alternative would have the advantage that soils with a continuous indurated layer having the minimum thickness required for a petrocalcic horizon and those having either a strongly fractured petrocalcic horizon or those having an indurated layer that does not satisfy the thickness requirements for a petrocalcic horizon would be grouped in the same great group.

DIAGNOSTIC HORIZONS OF CARBONATE AND GYPSUM ACCUMULATIONS

John E. Witty

The presence of carbonates or gypsum is an important criterion in classifying soils. But it is not easy to agree on limits between soil classes at various categorical levels for the amount, form, thickness of layers, and other features of carbonates or gypsum in soils. This paper discusses the diagnostic horizons of carbonate and gypsum accumulations defined and used in Soil Taxonomy (Soil Survey Staff, 1975) to identify classes at the great group or subgroup levels, as well as the hypergypsic and hypercalcic horizons suggested by Osman (1980). A description of each of the six horizons follows:

a. The calcic horizon is a horizon in which calcium carbonate or calcium and magnesium carbonate has accumulated. It must be at least 15 cm thick, have at least 5% more calcium carbonate equivalent than the original material, and have a total calcium carbonate equivalent of 15% or more unless the particle-size class is sandy, sandy-skeletal, coarse-loamy, or loamy-skeletal with less than 18% clay. A calcic horizon may show weak cementation, but air-dry fragments will slake in water.

b. The petrocalcic horizon is a horizon that has become plugged with carbonates and cemented; it is a hard, massive, continuous horizon. The petrocalcic horizon is a barrier to roots and is so strongly cemented that air-dry fragments do not slake in water. It must be thick enough that the product of its thickness in centimeters and the percentage of calcium carbonate equivalent is 200 or more.

c. The gypsic horizon is a horizon at least 15 cm thick that is enriched with secondary sulfates and has at least 5% more gypsum than the underlying materials. The product of its thickness in centimeters and the percentage of gypsum must be 150 or more. A gypsic horizon may be weakly cemented, but air-dry fragments slake in water.

d. The petrogypsic horizon is a horizon enriched with secondary sulfates that is so strongly cemented by gypsum that air-dry fragments do not slake in water and roots cannot enter. The petrogypsic horizon does not have a thickness limitation.

e. The hypercalcic and hypergypsic horizons were identified in Circular I of the International Committee on Aridisols (Osman, 1980) and proposed for possible establishment as two new diagnostic horizons in Soil Taxonomy. Circular I does not define these two horizons, but it implies that the definitions of calcic and gypsic horizons should give maximum limits of carbonate and gypsum, and that their contents in hypercalcic and hypergypsic horizons would exceed these limits.

DISCUSSION

Calcic and hypercalcic horizons

Osman (1980) did not propose a limit between the calcic and hypercalcic horizons, but a limit of 40% carbonate of the fraction less than 2 mm may reflect important differences in soil genesis. Gile and Grossman (1979) reported that a carbonate accumulation of more than about 40% in low-carbonate parent material resulted in a plugged, cemented, petrocalcic horizon. The hypercalcic horizon would then be comparable to the petrocalcic horizon in carbonate content, but would have less than 40% secondary carbonates and reflect a parent material high in carbonates.

It is doubtful, however, that the hypercalcic horizon is needed to identify classes of soils at the higher categorical levels in Soil Taxonomy. I do not know of any critical limit in calcium carbonate content for separating the two horizons that would be significant in interpretations made, for example, at the great group or subgroup levels. The Soil Survey Staff (1975) considered the presence or absence of a calcic horizon to have little importance for defining various classes of soils at the great group level in Aridisols. The calcic horizon is definitive for only one great group, the Calciorthids. All other great groups of Aridisols, except the Camborthids, may have a calcic horizon, but it is not a part of their definition. Other sets of properties associated with an argillic horizon, natric horizon, duripan, or other horizon were considered more important than those associated with a calcic horizon. At the subgroup level as well, an absolute amount of carbonate was not considered an important property for defining classes.

Petrocalcic horizon

The Soil Survey Staff (1975) recognized the petrocalcic horizon at the great group level, but made it subordinate to the salic horizon in combination with a high water table and a duripan. The petrocalcic horizon is recognized at a high level in Soil Taxonomy for two important reasons concerning soil use and management; it is a barrier to roots and has moderately slow to very slow hydraulic conductivity. Depending on its thickness and degree of induration, however, it may be destroyed by mechanical means to increase rooting depth and hydraulic conductivity.

The definition of the petrocalcic horizon is similar to that of other "pans," except that it allows for no cracks or fractures that roots might penetrate. To make the definition of a petrocalcic horizon parallel to the other definitions, a sentence should be added such as: "There may be fractures in the petrocalcic horizon, but the average lateral distance between fracture points is 10 cm or more."

Gypsic and hypergypsic horizons

The gypsic horizon has a definition parallel to that of the calcic horizon and, like the calcic horizon, is subordinate to many other sets of

properties in defining great groups of Aridisols. The gypsic horizon, however, does take precedence over a calcic horizon in that the Gypsiorthids can have a calcic horizon but Calciorthids cannot have a gypsic horizon. Compared to the calcic horizon, the gypsic horizon is relatively rare in other great groups of Aridisols.

At the subgroup level, this parallelism stops because: (a) there was not sufficient documentation of the extent and variety of Gypsiorthids to complete their classification, and (b) the distinction between Gypsiorthids with high and low gypsum content was made on the basis of assumed differences in soil behavior (Soil Survey Staff, 1975). The distinction between soils with high and low gypsum content supports establishment of a new diagnostic horizon such as the hypergypsic horizon.

Establishment of a new horizon, however, must be justified by soil behavior problems. In reviewing papers by Stoops and Ilaiwi (1981), Mousli (1981), and Mardoud (1981), one must conclude that for interpretations concerning crop production the form of gypsum is more important than the absolute amount. Some forms allow root penetration, good yields, and water percolation with gypsum content in excess of 50%; others act as a barrier to roots and water with as little as 25% gypsum. It seems that these distinctions relate much more to proper separation between the already defined gypsic and petrogypsic horizons than to problems of high gypsum content.

Highly gypsiferous materials are subject to subsidence or dissolution. In the Euphrates Basin, Mousli (1981) reports, holes of thousands of cubic meters occur in the material under some canals, and large irrigated areas with high gypsum content require extensive maintenance and leveling. In Saudi Arabia, on the other hand, the extent of Gypsiorthids being farmed is very small, and subsidence has not been a problem even where canals are in highly gypsiferous materials. The irrigation water is saturated with $CaSO_4$ and, therefore, it has a low dissolution capacity; this probably accounts for the lack of subsidence.

Several questions need to be answered. Is excessive subsidence due to high gypsum content in the soil -- or to gypsiferous materials in the substratum? At what depth is collapse initiated? Are there preexisting cracks, cavities, or caverns in the zones of collapse? If subsidence is due entirely to dissolution of the gypsum, approximately 5 m of water would have to percolate through the soil for every 1 cm of subsidence, assuming bulk density of about 1.3 g/cm^3 for the gypsiferous material and a very low concentration of Ca^{++} and SO_4^{--} ions in the applied water. If good water management practices are followed, soil material might be dissolved at a rate equivalent to 1 cm per 15 years, or less than 9 t/ha per year. At this rate, soil loss would be considered within acceptable limits, if loss by erosion is also minimal, and probably would not be noticeable from year to year. If, on the other hand, subsidence is the combined result of dissolution and of cracks, cavities, or caverns, it could be visually noticeable. Another question is whether these cracks, cavities, or caverns are within the pedon we classify or below it. If the properties that cause subsidence are not within the soil but are in gypsiferous materials below the soil, then the soil properties should not be used as criteria to identify the problem. The alternative is to identify the problem by a phase, such as "gypsiferous substratum" phase.

Petrogypsic horizon

The definition and description of the petrogypsic horizon in Soil Taxonomy are very brief and probably lead to misinterpretation. In Saudi Arabia, extensive areas of soils have horizons with high gypsum content. But the extent of soils recognized in recent soil surveys as having a petrogypsic horizon is small. A report by Groundwater Development Consultants (International), Limited (no date), who mapped in the Eastern Province, stated that "some crystalline gypsum does not slake in water but crumbles easily on touching after wetting and allows some roots to enter. Only the hardest, most compact crystalline gypsum horizons have been termed petrogypsic here, and those are of very limited extent in the Study Area." In the Reconnaissance Soil Survey of Wadi Dawasir, Robinson and Miller (1980) used similar criteria to recognize the petrogypsic horizon. The only soil classified as having a petrogypsic horizon was described as underlain by extremely hard, indurated sand and gravel cemented with gypsum and lime.

This soil probably represents an extreme development of a petrogypsic horizon or a relict feature that might better be described as rock. Eswaran et al. (1981) describe the micromorphological nature of the petrogypsic horizon as follows: In some petrogypsic horizons ". . . packing results in some cementation between adjoining grains, leading to the rigidity of the material," and in others ". . . the crystals are massive and interlocked." From this description it appears that the petrogypsic horizon can be fragile in early stages of its development and very compact in later stages.

Some gypsiferous horizons that I have examined can easily be dug through with either spade or auger. The gypsic material comes out as chunks but easily breaks to gravel-size clusters of crystals. Whenever I have discussed these soils with others in the field, the consensus has been that the horizon in question was probably not petrogypsic by definition. The interlocking of the gypsum crystals, however, probably restricts roots and the horizons should properly be called petrogypsic. But very little research has been conducted on gypsiferous soils in Saudi Arabia. In general they are believed to have low potential for irrigated agriculture, and to date there has been little pressure to farm them on a large scale.

SUMMARY

The hypercalcic horizon described by Osman (1980) probably should not be established for use in defining new classes at the great group or subgroup level. The calcic horizon is thought to be adequately defined, but a statement should be added to the definition of the petrocalcic horizon concerning average spacing allowed between fractures that roots might penetrate.

As for the hypergypsic horizon (Osman, 1980), absolute gypsum content is relatively unimportant in crop production, compared to its form and whether it acts as a barrier to roots and water. A hypergypsic horizon established to define classes at the great group or subgroup level would have low interpretive value if the excessive subsidence occurs only where highly gypsiferous materials are below the soil. It would have high interpretive value if the

characteristics that cause excessive subsidence are within the soil, but I believe that these characteristics generally are in the substratum.

In Saudi Arabia and possibly elsewhere, weakly developed petrogypsic horizons may have been misidentified as gypsic horizons. As a result, the extent of Petrogypsic Gypsiorthids may have been underestimated. Refining the definition of the petrogypsic horizon should improve uniformity of application and reliability of classification.

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IMPROVED MANAGEMENT SYSTEMS FOR VERTISOLS IN INDIA

S.M. Virmani, J.R. Burford, and K.L. Sahrawat

Vertisols are potentially one of the most productive soils for rainfed agriculture in the semi-arid tropics (SAT). Their high water-holding capacity endows them with the ability to compensate better than most other soils for the low and erratic rainfall, which is a major constraint for crop production and growth, or sometimes even survival.

Because of the high potential of Vertisols for increased productivity, ICRISAT has given a high priority to developing improved farming systems for these soils. Here we describe these systems and the environment that has led to their development. Particularly relevant is the fact that India and the Sudan contain a significant proportion of the world's Vertisols; characterizing the soils and agroclimates should indicate areas with potential for transfer of appropriate elements of improved technologies.

THE ENVIRONMENT

The single most important characteristic of Vertisols - high water-holding capacity - results from their high content (>30%, and commonly 60-70%) of dominantly montmorillonitic clay, and a deep profile (usually >70 cm for vertic properties to be fully expressed). Other important characteristics related to the high water-holding capacity and the associated swelling and shrinking are the cracks that develop (and facilitate rapid infiltration of water to the deeper layers) and the "self-mulching" of some surface soils, which facilitates seedbed preparation. When the soil is dry, infiltration is initially rapid, but declines rapidly as moisture content of the surface soil increases. Then, high-intensity storms can cause appreciable runoff and waterlogging where surface drainage is inadequate.

Soil characteristics are given in Table 1 for a profile of the Kasireddipalli series, on which ICRISAT's improved farming systems for deep Vertisols were developed. Murthy et al. (1982) have listed characteristics of the Vertisols in India.

Gilgai formation which is a characteristic of some Vertisols appears to be less pronounced in India than elsewhere in the world. Cultivation for long periods in the past, by causing some levelling of the soil surface, may have contributed to the general lack of marked surface microrelief.

Table 1. Some characteristics of a typical Vertisol at ICRISAT Center.[a]

Horizon	Depth (cm)	Particle-size distribution %			pH (1:2.5 water)	$CaCO_3$ (%)	Organic C (%)	CEC (me/ 100 g)
		Sa	S	Cl				
A_p	0-20	23	23	54	3.8	5.3	0.73	57
A_{12}	20-40	22	22	56	9.2	7.4	0.54	59
A_{13}	40-60	20	22	58	9.4	7.0	0.47	56
A_{14}	60-90	16	24	60	9.4	6.3	0.39	60
AC	90-130	12	21	67	9.4	6.2	0.28	63
C	130-180	13	20	67	9.4	7.5	0.25	62

[a]Kasireddipalli series; Typic Pellustert - very fine, montmorillonitic, isohypothermic.
Location: Field BW7.

Source: Murthy et al. (1982).

Climate

The semi-arid tropics (SAT) are approximately delineated by mean annual temperatures exceeding 18°C, and two to seven consecutive humid (P>ET) months. Average monthly rainfall, however, provides only a crude assessment of agro-climate within the SAT. The rainfall regime is much better described by the reliability of rainfall, calculated over week-long periods. For example, in India, Hyderabad and Solapur have total annual rainfalls of 761 and 765 mm, but the probability of receiving 10 mm or more of rain per week throughout the rainy season (southwest monsoon) is about 70% for Hyderabad but only 50% for Sholapur. The probability of a successful rainy-season crop, calculated from a water-balance model, is about 62% at Hyderabad but only 33% at Sholapur (Binswanger et al., 1980).

RESPONSE TO THE ENVIRONMENT AND ASSOCIATED PROBLEMS

The Indian farmers' traditional system

In the Indian SAT, the traditional cropping patterns on Vertisols and associated soils can be related to constraints imposed by the combination of agroclimatic and soil characteristics. On the shallower (vertic) soils, cropping is confined to the rainy season because the limited water-storage capacity will not support growth for long after the rains cease. On the deep Vertisols (1-1.5 m), however, cropping patterns and land use vary. Some are cropped during the rainy season with local cultivars whose growth extends beyond the end of the rainy season. But many deep Vertisols (perhaps 50%, Krantz et al., 1975) are left fallow during the rainy season, and used only for a single crop grown on stored moisture in the postrainy season.

Not cropping during the rainy season appeared to be inefficient use of resources. Initial observations by Krantz and Kampen (Kampen, 1982) indicated that not cropping during the rainy season could be attributed to both too much and not enough soil moisture; this was subsequently confirmed by Virmani et al., (1981) and Michael (1981), whose analyses showed that the rainy season fallows can be separated into:

"Dry" fallows: those with unreliable rainfall during the rainy season, so that bare fallowing is essential to attempt to accumulate enough water to produce a crop in the postrainy season on stored water (as exemplified by Sholapur).

"Wet" fallows: those with adequate to excessive rainfall during the rainy season risk losses from waterlogging and flooding. Crops grown in the postrainy season usually have enough moisture to produce a crop because rainfall is usually sufficient to fully charge the profile, but productivity is low (as exemplified by Hyderabad).

Where rainy-season fallow is practiced, common postrainy-season crops are sorghum, wheat, chickpea with some sorghum/oilseed intercropping, and wheat-chickpea or wheat-linseed on a two-year rotation (Krantz et al., 1975). Less common, but still important, are a few specialty crops like chillies.

Where crops are grown during the rainy season, many crops are used, and in many combinations; multiple cropping as well as sole cropping is practiced (Spratt and Choudhury, 1978; Willey, 1979). Sorghum or cotton is commonly grown in association with a sparse pigeonpea intercrop. Sequential crops may be sorghum in rainy season followed by chickpea in postrainy season. But full use of the land by two crops spanning both seasons is rare (on less than 10% of the deep Vertisols, Krantz et al., 1975).

The farmers' chief implements on those soils are a single "pointed-stick" plough and a blade harrow (bakhar); seed is broadcast or placed through a seed tube attached to the plough. The only nutrient input is occasional small applications of farmyard manure. Cultivars are usually long-season. tall, local varieties with characteristically low harvest indices.

Because inputs are low and productivity is reasonably stable, loss risks are low. The low-yield, low-risk system was satisfactory before population pressures required increasing productivity per unit area.

The Indian farmers' traditional system has several major problems and limitations: poor internal drainage of the heavy soils severely restricts operations during the rainy season, especially when rainfall is excessive or the land's slope is minimal; cultivation equipment lacks versatility; crop cultivars, although resistant to some pests and diseases, lack yield potential and ability to respond to such inputs as fertilizers. Crop options often are limited because long duration cultivars are used. The most serious deficiency of the rainy season-fallow system is that it promotes erosion, which is several-fold greater on fallows than on soils protected by a growing crop; continuing erosion will cause a reduction of a valuable resource, viz. the depth of soil. Shallow soils do not permit extended cropping in the postrainy season, because of their limited moisture storage capacity.

ICRISAT's improved farming systems

To improve productivity of the land, ICRISAT developed a double-cropping system that uses both the rainy and the postrainy season. Each of the two crops is more productive than the farmers' traditional single crop. Basic elements of the ICRISAT systems are:

- Shaping land to dispose of excess water by the broadbed-and-furrow system and grassed waterways;

- "Rough" ploughing of land immediately after harvest when some moisture remains in the soil;

- Completing seedbed preparation after the first premonsoon rain (between harvest in January/February and onset of the southwest monsoon in June);

- Dry sowing crops before, but within two weeks of, the arrival of the southwest monsoon in June;

- Using improved cultivars in improved cropping systems that allow farmers to choose among sole crops, sequential crops, and intercrops;

- Fertilizing with N and P and sometimes Zn; and

- Precisely placing fertilizer and seed and correctly timing nitrogen applications.

The developments have involved much basic work, for example: identifying areas of assured rainy-season rainfall and also areas where dry seeding can be used; selecting improved crop species, cultivars, and combinations of crops; developing simple bullock-drawn equipment; and developing the land-shaping methodology.

Yield increases under the system have been substantial. The improved intercropping system gave yields of 3,000 kg/ha of cereal (maize or sorghum) and 1,000 kg/ha intercropped legume (pigeonpea) on operational research areas at ICRISAT Center, compared with 500-800 kg grain/ha for a farmer's single crop of sorghum or pigeonpea. Pigeonpea commonly sells for three times as much per kg as sorghum, thus making the total yield the cash equivalent of approximately 6,000 kg/ha cereal grain. A sequential crop of cereal (rainy season) followed by postrainy-season crop (chickpea, safflower, etc.) gave comparable but slightly less stable productivity because of greater risks associated with establishing the second crop (Willey, 1979). Ryan and Sarin (1981) reported that the profitability resulting from introducing both cropping systems was excellent, with net profits increased 500-600% and a return of ca. 250% from the additional funds invested.

The crop combinations quoted are those that have been consistently successful. Other combinations are being investigated, and the most promising will be used to provide other options for farmers. It is essential to provide options to allow for the preferences of individual farmers and for various diseases, pests, agroclimates, and soils over the target area.

After the double-cropping technology had been tested and modified at ICRISAT over a period of several years, it was evaluated by farmers on their own from 1981. The preliminary results are encouraging (Ryan et al., 1982).

TRANSFER OF TECHNOLOGY

Farming systems research is commonly stated to be site specific. Site specificity, however, reflects a lack of characterizing soil and agroclimate at experimental sites throughout the SAT regions and a lack of understanding of the relationships between environmental factors and the productivity of crops. Our research strategy involves "transfer of results by analogy," i.e. extrapolating "representative" site data to surrounding areas with similar properties (Nix, 1968), which requires good descriptions of the soils and agroclimate at both the experimental and the transfer sites.

Improvements in descriptions of climatic and soils environments in the Indian SAT are being emphasized. We now have agroclimatic delineation of the areas in the Indian SAT where the rainy-season rainfall is sufficiently reliable to assure growth of crops in the rainy season, and where the onset of the southwest monsoon in June can be predicted for the dry seeding of crops. This information, together with the estimated extent of the areas

of deep Vertisols, lets us assess areas in the Indian SAT suitable for the improved farming systems technology. Of the total ca. 72 million ha of Vertisols and related soils in India, about 12 million fulfill the agroclimatic and soil requirements for the improved farming systems.

The accuracy of predictions in India will improve as better descriptions of soil resources become available; already, several major soil series of deep Vertisols have been identified, and each series covers substantial areas (Murthy and Swindale, unpublished data). The continuing improvements in soil and agroclimatic resource descriptions within India will help us attempt to identify areas with similar agroclimates and soils in the Sudan.

The Vertisol area in Sudan (Fig. 1) is ca. 63 million (FAO-UNESCO, 1977), approximately 25% of its total 250 million ha area (NOA, 1975). Table 2 gives data on selected agroclimatic characteristics of sites in or near Vertisol regions of Sudan and India. Some 15 locations in the Sudan have been studied in detail, too few for detailed climatic classification work but enough for initial generalizations. Combining the soils and agroclimatic data shows the area occupied by Vertisols and receiving dependable rainfall (>2 months) in the Sudan; this covers approximately 42 million ha or 67% of Sudan's Vertisols (Fig. 1).

The limited agroclimatic and soils data available on the Sudan let us speculate that the principles of our present improved soil management practices may well be applied over the entire area. The crop and crop-management component could apply to the area of 30 million ha with ca. 3-5 humid months where the growing season averages 20-30 weeks, and appears to be more reliable than ICRISAT's rainy season. The climatic environments at Malakal and at ICRISAT Center appear quite similar. In calculations of the growing season, we assumed that rainfall exceeding the soil's water-holding capacity is lost as runoff.

This optimistic outlook for the Sudan undoubtedly will require some modification because our present observations are only a first approximation. Experience there will undoubtedly reveal other constraints. To more accurately predict the applicability of the components of our existing Vertisol technology to the Vertisols in the various subregions of the Sudan, we now need detailed analyses of the soils, climate, and socioeconomic features of the Sudan.

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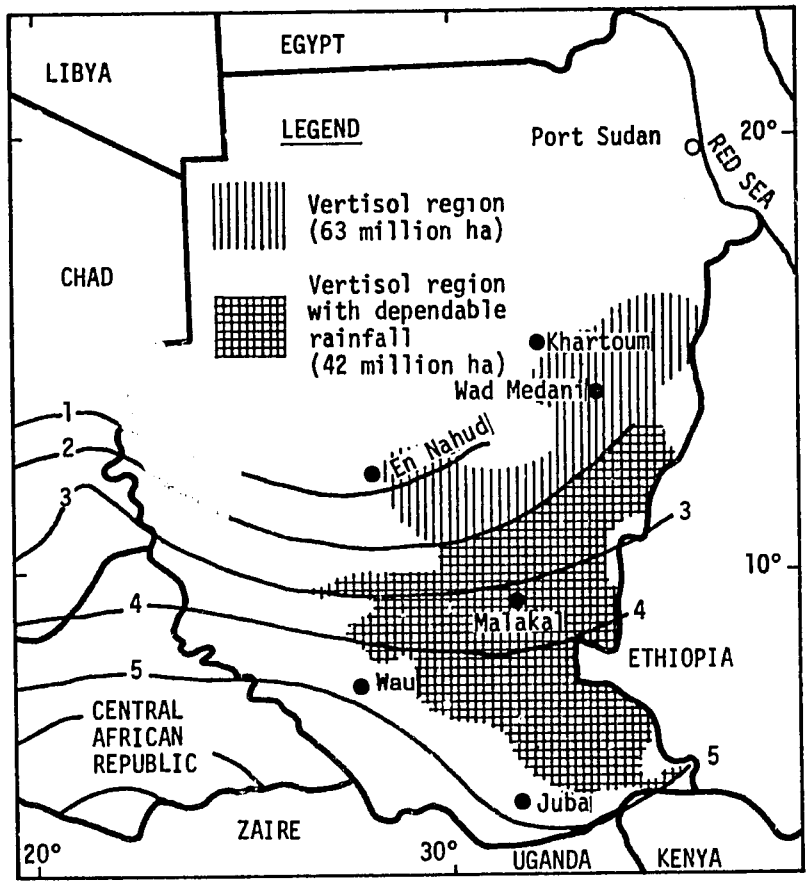
Figure 1. Sudan Vertisol region



SOURCE: FAO-UNESCO Soil Map of the World. 1977.

Table 2. Selected climatic characteristics of some Vertisol regions of Sudan and India.

Location	Latitude	Longitude	Elevation (m)	Rainfall (mm) Annual	Rainfall (mm) Seasonal	Rainy months From	Rainy months To	P.E.T. (mm) Annual	P.E.T. (mm) Rainy Season	Length of Growing Season (weeks)
Sudan										
Khartoum	15.36°N	32.33°E	380	164	147	Jul	Sept	2228	592	< 4
Wad Medani	14.24°N	33.29°E	408	373	306	Jul	Sept	2011	512	6
En Nahud	12.42°N	28.26°E	564	423	332	Jul	Sept	1990	490	6
Malakal	09.33°N	31.39°E	388	783	579	Jun	Sept	1834	575	16
Mau	07.42°N	28.01°E	438	1145	914	May	Oct	1445	664	26
Juva	05.42°N	31.36°E	457	982	876	Apr	Oct	1495	806	30
India										
Hyderabad	17.27°N	78.28°E	545	761	653	Jun	Oct	1750	625	18
Poona	18.32°N	73.51°E	559	715	615	Jun	Oct	1474	579	18
Nagpur	21.06°N	79.03°E	310	1251	1143	Jun	Oct	1773	683	20
Indore	22.43°N	75.45°E	567	1127	949	Jun	Sept	1813	600	20
Akola	20.42°N	77.02°E	282	877	755	Jun	Sept	1730	600	20

[a]Data used pertain to Yeotmal.

Sources: IMD, 1967
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SOIL FERTILITY MANAGEMENT IN RELATION TO AGRICULTURAL PRODUCTIVITY IN VERTISOLS OF INDIA

A.S.P. Murthy, D.P. Viswanath, and M.N. Sheelavantar

ABSTRACT

Vertisols are highly fertile soils; their productivity rating has been low, partly due to management problems and deficiencies in irrigation and supplies of plant-available nutrients.

Vertisols are low in organic matter and N status. Response of crops on Vertisols to added N was found to be better with phosphatic and/or complex fertilizers. The efficiency of nitrogen usage can be improved with the addition of organic matter and/or well-decomposed manure.

Addition of farm residues like deoiled neem cake, cotton, and maize stalks just before the sowing of the monsoon crop under irrigation enhances grain yields of crops and appears to have good P and K residual effect on the post-monsoon cereal wheat which was raised with half the dose of N required and no P and K fertilizers added. This amounts to considerable savings in N, P, and K fertilizers and the added residues apparently play a significant part in increasing the availability of native and applied P in soils.

Though there is no yield response of crops to added potassium, there appears to be a possibility of modifying the adverse soil physical properties by the addition of potassium.

Response of crops to micronutrients will be better in the presence of moderate amounts of fertilizers and a mixture of micronutrient elements like Zn, Mn, and Fe.

Although the actual yields are low in the farmer's field, results from research stations as outlined in this review amply demonstrate that Vertisols have a high yield potential, and future food needs of India can be met by using the right combination of crop varieties, cropping systems, fertilizers, micronutrients, recycling crop residues, and irrigation.

INTRODUCTION

Vertisols and associated soils occur in peninsular India covering 73 mha of the total geographic area of India of 328 mha and 0.55% of the world's land area (Murthy, 1981; Buringh, 1982; Dudal, 1965). Vertisols constitute nearly 21% of potential cropped area as against 51% of the potential available land in India. These soils have the maximum potential grain equivalents (MPGE) of 1235 million tons per year (Table 1) representing nearly 2.5 and 27% of world and India's MPGE, respectively (Swaminathan, 1980).

Table 1. Actual and potential agricultural land (10^6) inclusive of Vertisols.

	ACL	AIL	PAL	PIAL	PCA	MPGE
World	1402	201	3419	470	3270	49830
	(200)	-	(140)	-	(150)	-
India	143	34	143	77	281	4572
	(40)	(10)	(73)	(20)	(60)	(1235)

Number in parenthesis represents the values for Vertisols.

Source: Swaminathan (1980); Buringh (1982).

ACL = Actual cultivated land (10^5ha)
AIL = Actual irrigated land (10^6ha)
PAL = Potential agricultural land (10^6ha)
PIAL = Potential irrigated agricultural land (10^6ha)
PCA = Potential cropped area
MPGE = Maximum potential grain equivalents (10^6t/year)

Though agriculture in the tropics was first developed in areas of high base status soils of which Vertisols constitute an important soil order, the potential of Vertisols for food production has been viewed with a certain amount of skepticism because of inherent adverse soil physical properties and deficiencies in supplies of irrigation and available plant nutrients. The grain potential of these soils and the differential yield of crops under rainfed and irrigated conditions shown in Figs. 1 and 2 indicate that Vertisols could possibly bridge the projected food grain requirement of 200-225 million tons by 2000 A.D.

This paper attempts to: (1) highlight the constraints to soil fertility and fertilizer use that are limiting crop yields; and (2) show how hitherto unproductive Vertisols can be exploited through manipulation of management variables such as selection of fertilizer-responsive crops, fertilization, recycling of crop residues and irrigation, for meeting the future food needs of India.

ORGANIC MATTER AND CROP RESIDUE MANAGEMENT

Organic carbon content in Vertisols of India is low, ranging from 0.4 to 0.7 in spite of their dark color. A great deal of emphasis was laid in the past on maintaining a stable organic matter level in soils for proper maintenance of physical properties necessary for sustained and stable crop production. Earlier work carried out by Raheja et al. (1971) and Puranik et al. (1978) has shown that continuous cropping and manuring resulted in higher organic carbon and nitrogen contents in black soils of India. Also, studies carried out by these authors and the research work carried out by the Advance Centre for Black Soil Research in the recent past indicate that agricultural productivity can be stepped up by suitable cropping systems and recycling of crop residues like deoiled neemcake, cotton and maize stalks. The results of investigation in this regard are shown in Figs. 3, 4, and 5.

Incorporation of cotton and maize stalks in Vertisols under irrigation with 100 N, 75 P_2O_5, and 37 K_2O kg/ha in two locations resulted in an increase

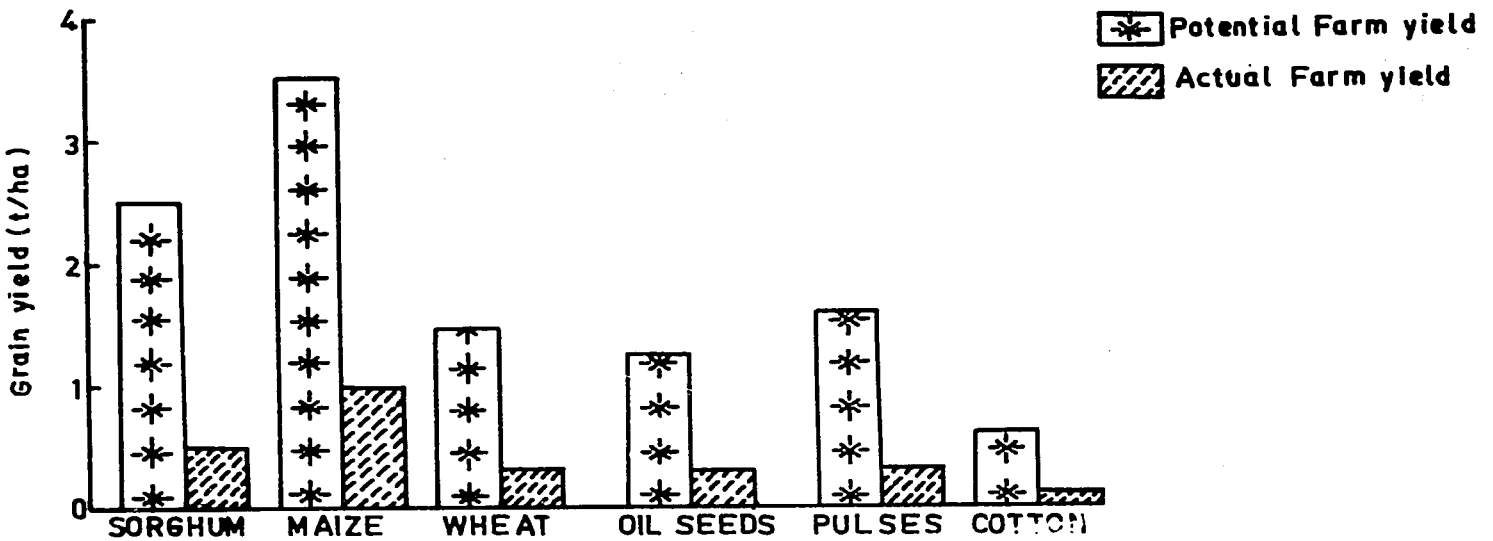

Figure 1. Yield potential of various crops under rainfed and irrigated conditions. (Source: Ann. Rep. AICRP Water Management, ICAR, New Dehli, 1979-81.)

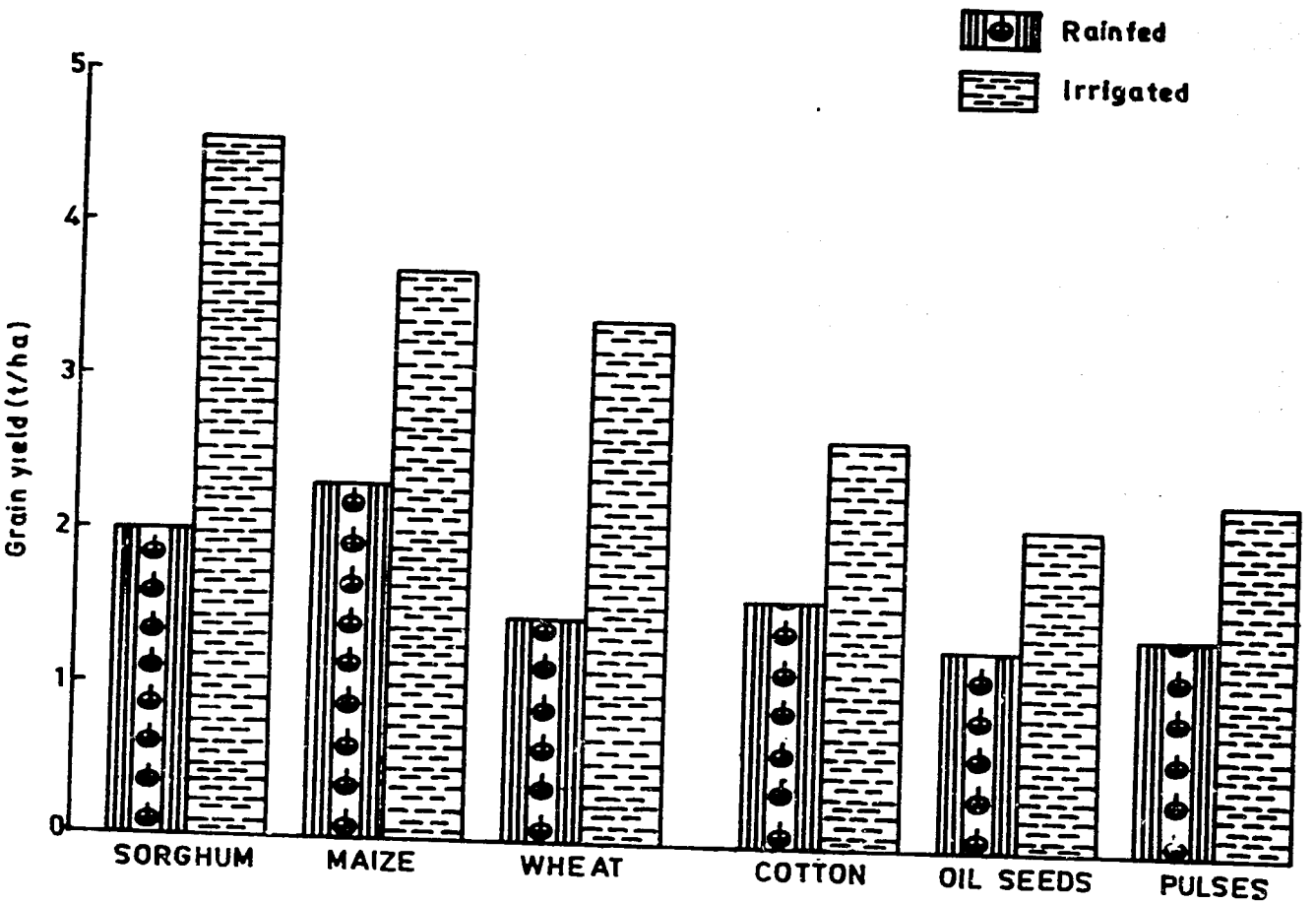

Figure 2. Yield gaps in dryland agriculture on Vertisols. (Source: Dryland Agric. Res. Prog. Rep., ICAR, 1977.)

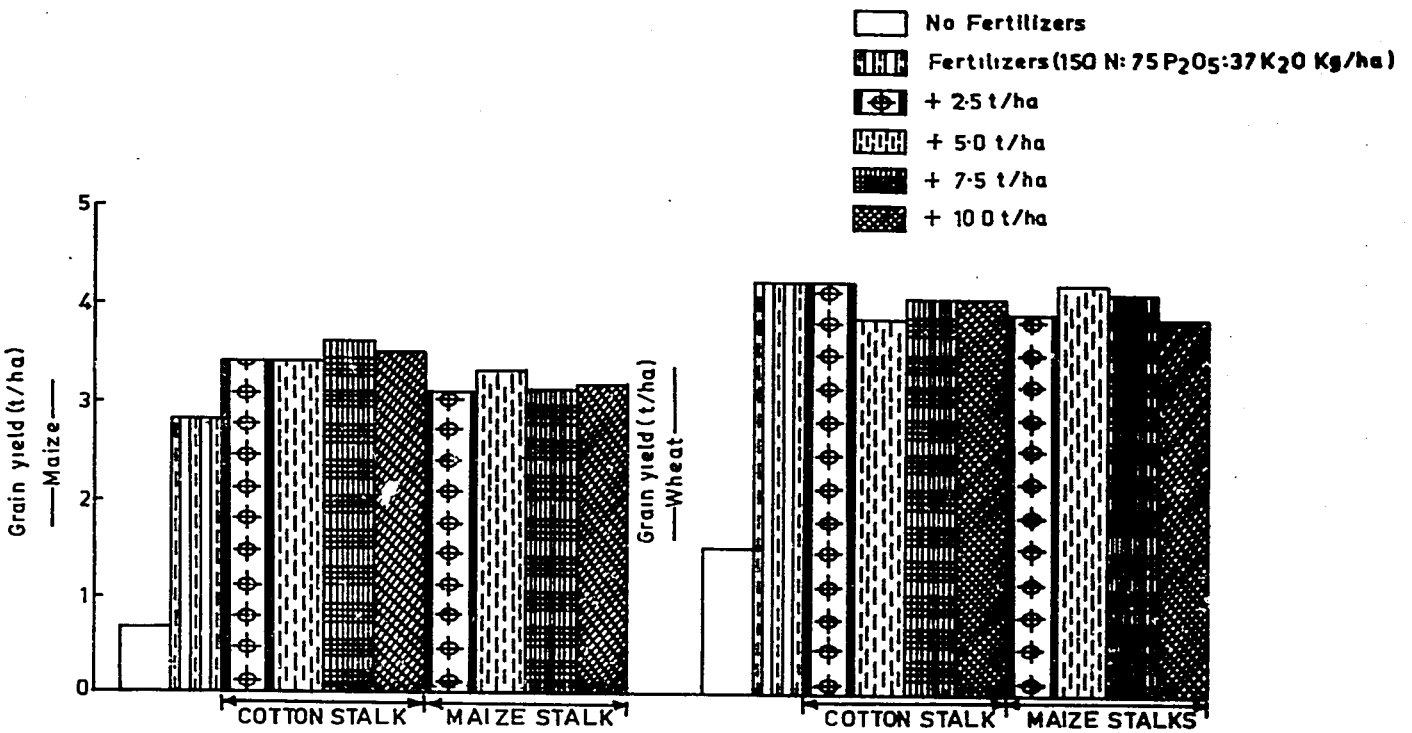

Figure 3. Grain yields of maize and wheat as affected by fertilizer and crop residue applications to Vertisols (Typic Chromuderts) under irrigation at Dharwad, India. (Source: Ann. Rep. Adv. Centre for Black Soil Res., Dharwad, India, 1978-1980.)

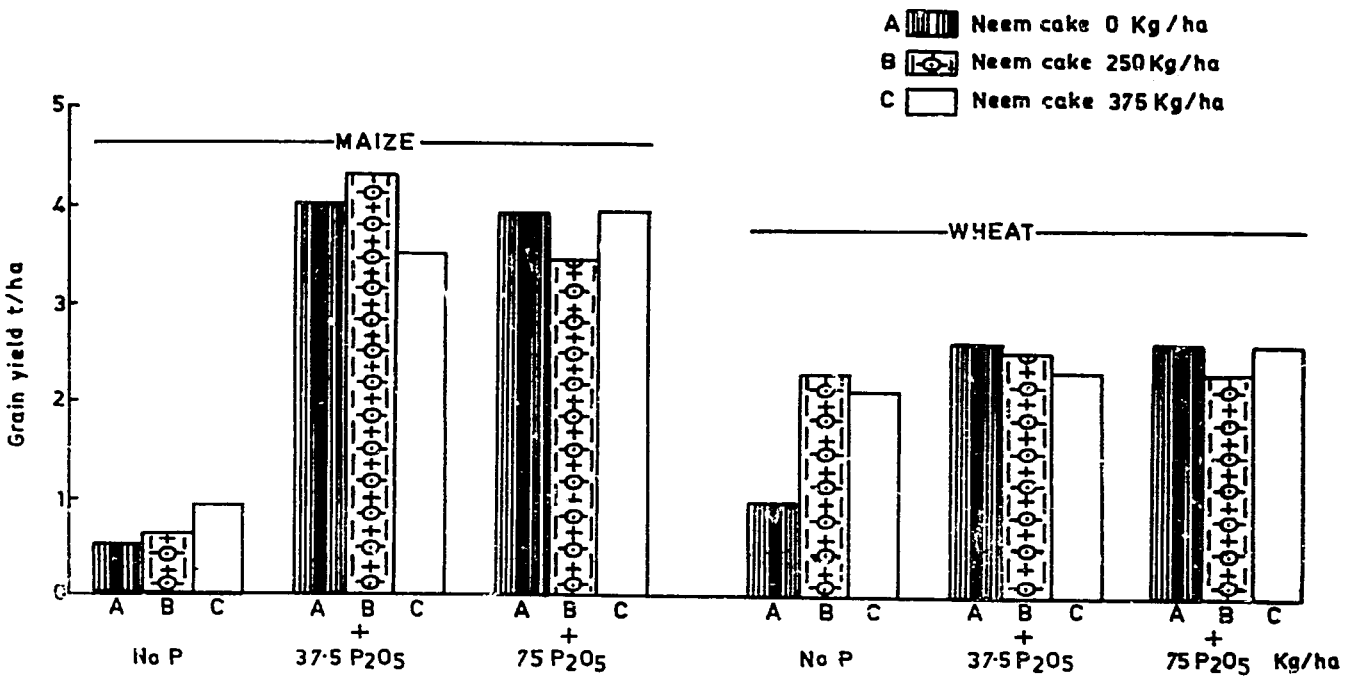

Figure 5. Grain yields of maize and wheat as affected by graded doses of neem cake and fertilizer P in Vertisols (Typic Chromuderts) under irrigation, Dharwad, India. (Source: Ann. Rep. Adv. Centre for Black Soil Res., Dharwad, India, 1979-81.)

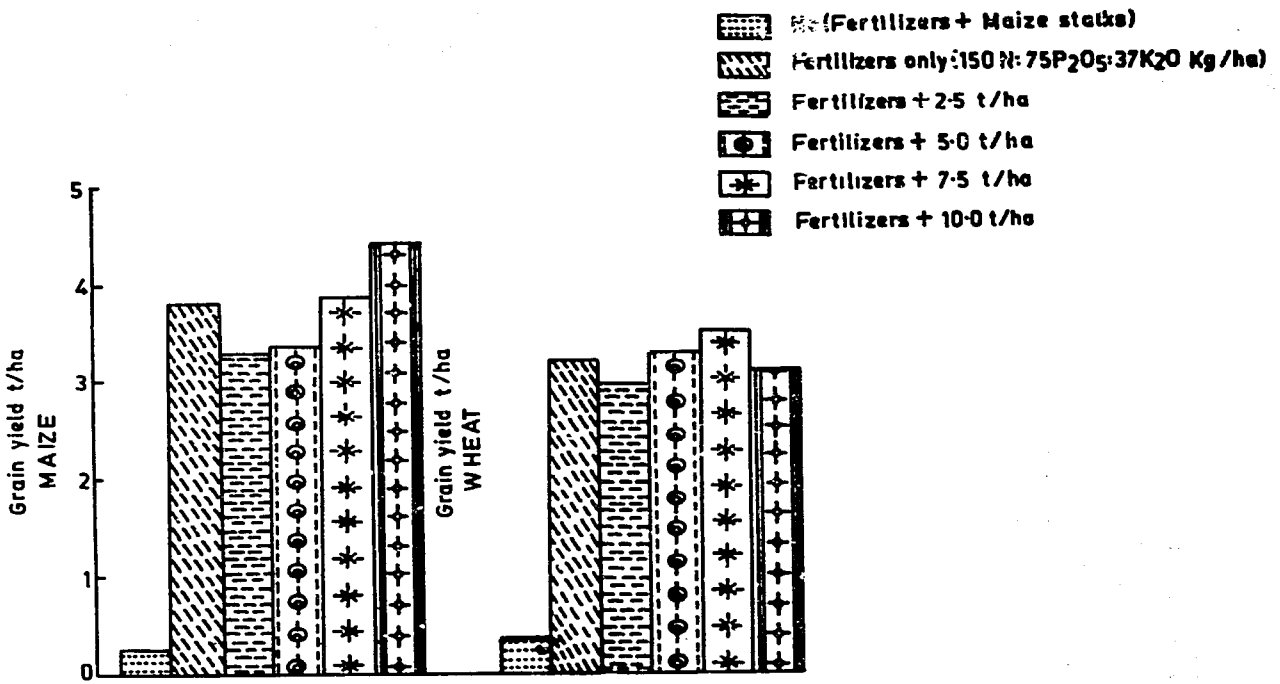

Figure 4. Maize and wheat grain yields as affected by fertilizers and maize stalk application to Vertisols (Typic Chromusterts) under irrigation. (Source: Ann. Rep.. Adv. Centre for Black Soil Res., Dharwad, India, 1979-1980.)

in maize yield of 13 and 15% on the College farm, Dharwad and Navalgund, India, respectively. Residual effect of these wastes were also studied on the succeeding post-monsoon wheat crop and it was found beneficial from the point of view of total yields of cereals for the cropping year. Furthermore, the post-monsoon crop was grown with only 50% of N and without the addition of the required P and K fertilizers.

An analysis of the cost-benefit ratio due to the incorporation of cotton stalks (2.5 t/ha) to Vertisols of Dharwad was 1:13 (Fig. 6).

An evaluation of the recycling potential of maize and cotton stalks in relation to the harvest of crops grown on the waste-treated site indicate that these residues are not detrimental to the ability of Vertisols to produce more food.

MANAGEMENT OF MAJOR- AND MICRONUTRIENT ELEMENTS

Nitrogen

The total N content in Vertisols of India is about 0.08%. Results of many agronomic experiments show the need for fertilizer N and also show poor utilization of N by crops.

Venkataswaralu (1979) observed that cereals grown during monsoon respond better to N than cereals grown during post-monsoon period (Tables 2 and 3). The response of sorghum to N was more in Vertisols of Bijapur (35%) and Akola (43%) as compared with the response in Vertisols of Sholapur and Rajkot. Vertisols of Bijapur and Akola possess a very high native soil fertility and are of basaltic origin. Total rainfall received in these areas is more than 300 mm as compared to 250 mm and below in Rajkot and Sholapur.

Studies made independently by Nagre and Khedekar (1979) at Akola, Maharashtra and the scientists of the Sorghum Research Project, Dharwad, Karnataka, India, reveal a significant response of varieties and/or hybrids to applied N in Vertisols. Hybrids like CSH-1 and CSH-5 were found to be more responsive to N over varieties. Among the hybrids, CSH-5 yields were better over CSH-1. Grain yield of CSH-5 was 1.8 t/ha at Akola and 3.6 t/ha at Dharwad. These yield differences could be attributed to variation in moisture regime, soil type, and crop varieties and/or hybrids (Figs. 7a and 7b).

Besides fertilizer-responsive varieties and/or hybrids, proper moisture regime, addition of organic manures, and crop residues could improve the efficiency of N usage. More et al. (1977) and Patil and Patil (1975) report that leaching and volatilization losses of ammonia in Vertisols were more with straight fertilizers like urea and ammonium sulphate, with maximum volatilization loss on the 12th day after the application of fertilizer N (Fig. 8). The losses of ammonia were less when complex fertilizers like uramphos and suphale were used. Further, the authors observed a significant reduction in losses of ammonia due to the addition of organic matter and/or well-decomposed farmyard manure (Fig. 9a).

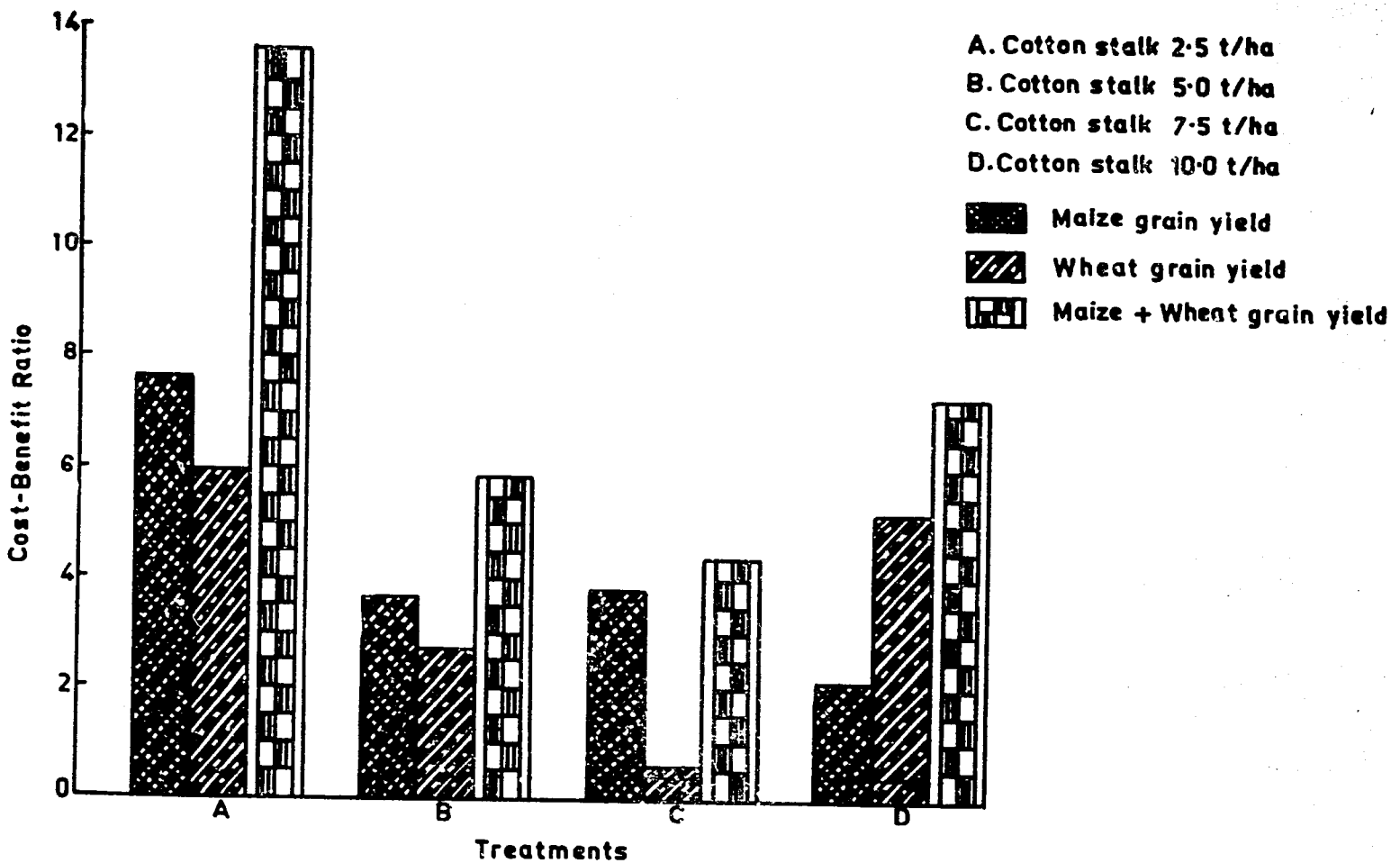

Figure 6. Recycling potential (cost-benefit) ratio of cotton stalks on cereal grain yields in Vertisols (Typic Chromuderts) under irrigation, Dharwad, India. (Source: Ann. Rep. Adv. Centre for Black Soil Res., Dharwad, India, 1978-80.)

Table 2. Sorghum grain yields (t/ha) in response to N in Vertisols of India.

Location	Nitrogen applied (kg/ha)					
	0		30		60	
	Monsoon	Postmonsoon	Monsoon	Postmonsoon	Monsoon	Postmonsoon
Bijapur	0.95	2.40	2.00 (35)	2.52 (4)	2.23 (7.7)	3.07 (18.0)
Sholapur	0.52	-	1.36 (28)	-	2.01 (21.7)	-
Akola	2.97	-	4.71 (43)	-	5.76 (26.0)	-
Rajkot	1.84	-	2.92 (36)	-	3.62 (23.0)	-
Bellary	-	0.87	-	1.14 (7)	-	1.30 (2.0)

Source: Venkateswaralu (1979).

Numbers in parenthesis indicate incremental responses expressed as kg grain per kg N applied.

Table 3. Grain yields (t/ha) of hybrid sorghum (CSH-5) and wheat (UP 301) in response to applied N and P in Vertisols under irrigation.[a]

Fertilizer N (kg/ha)	P_2O_5 kg/ha			
	45	60	90	120
		Sorghum		
75	7.6	7.1	6.9	7.4
100	7.6	7.7	7.7	7.3
125	7.5	7.8	7.3	7.1
		Wheat[b]		
75	1.3	1.3	1.4	1.3
100	1.4	1.6	1.5	1.6
125	1.5	1.6	1.7	1.6

Source: Ann. Rep. Advance Centre for Black Soil Research, University of Agricultural Sciences, Dharwad Campus, Karnataka, India.

[a]30 kg K_2O/ha was common to all the treatments.

[b]After the harvest of sorghum, 75 kg N and 45 kg P_2O_5/ha was given.

Patil and Patil (1975) observed a marked reduction in leaching losses of NO_3^- and NH_4^+-N due to cropping. The authors also observed a significant increase in the accumulation of NO_3-N in the fallow and a sudden decline in NO_3-N from 10 to 5 ppm due to cropping. This apparently indicates greater utilization of NO_3-N by the crop (Fig. 9b).

These studies indicate that the efficiency of N usage can be improved with the use of organic manures, complex fertilizers and continuous cropping. These methods are more effective than the costly deep placement of N.

A recent N fertilization experiment carried out by the Advance Centre for Black Soil Research, Dharwad, Karnataka, India and the work of Venkateswaralu (1979) in Vertisols indicate that for efficient management of N and increased crop yields, N has to be applied with phosphatic fertilizers (Table 3).

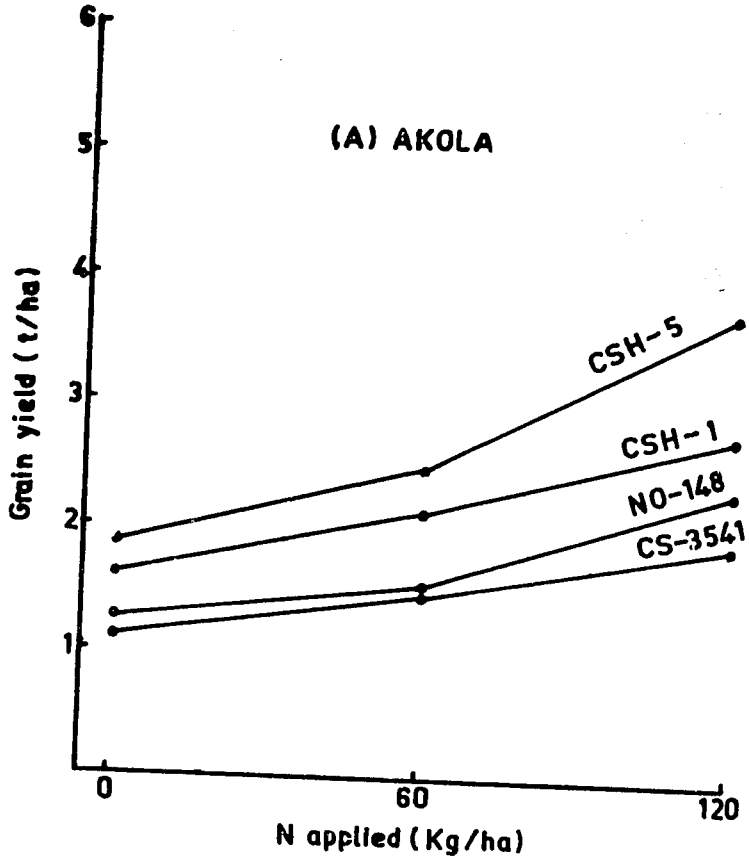

Figure 7a. Differential response of sorghum genotypes to nitrogen levels in Vertisols. (Source: Nagre and Khedekar, 1979; Ann. Rep. AICRP-Sorghum, 1979-80.)

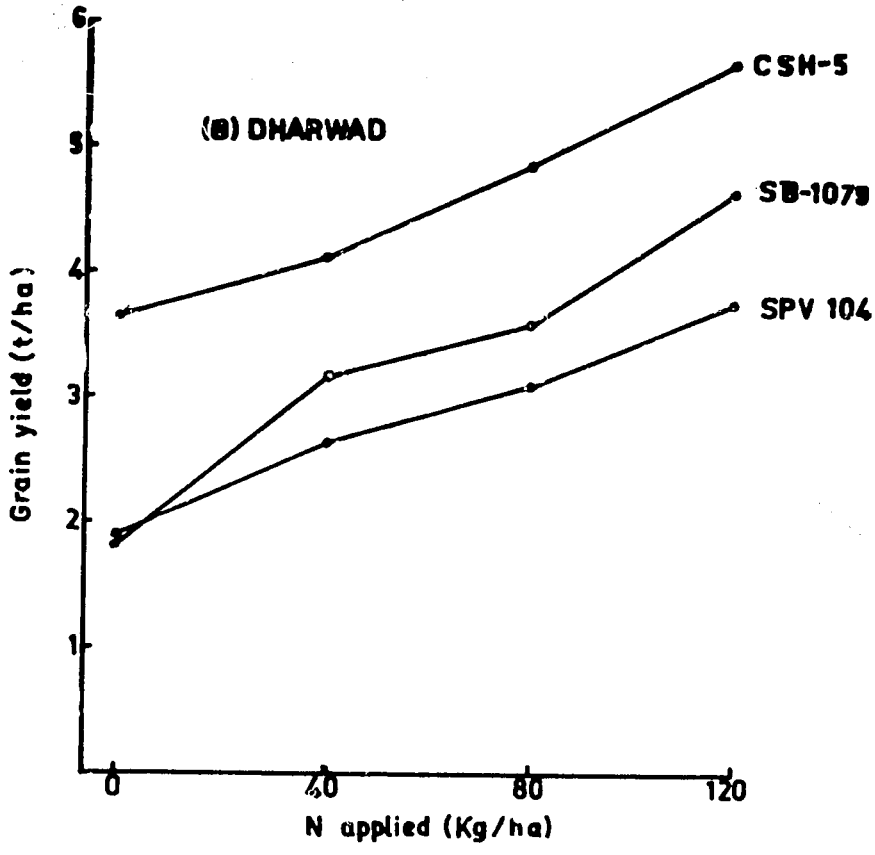

Figure 7b. Differential response of sorghum genotypes to nitrogen levels in Vertisols. (Source: Nagre and Khedekar, 1979; Ann. Rep. AICRP-Sorghum, 1979-80.)

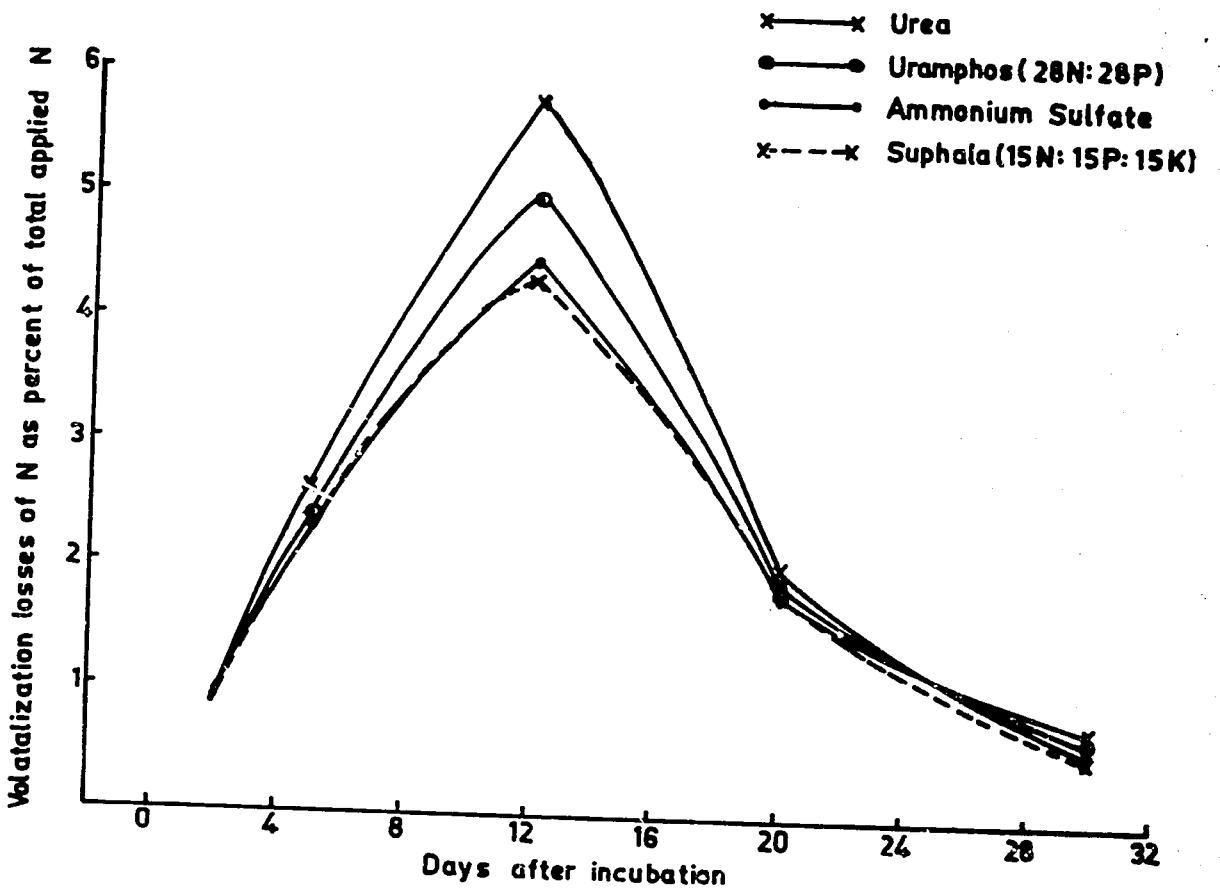

Figure 8. Ammonia loss from Vertisols as affected by N. (After More et al., 1977.)

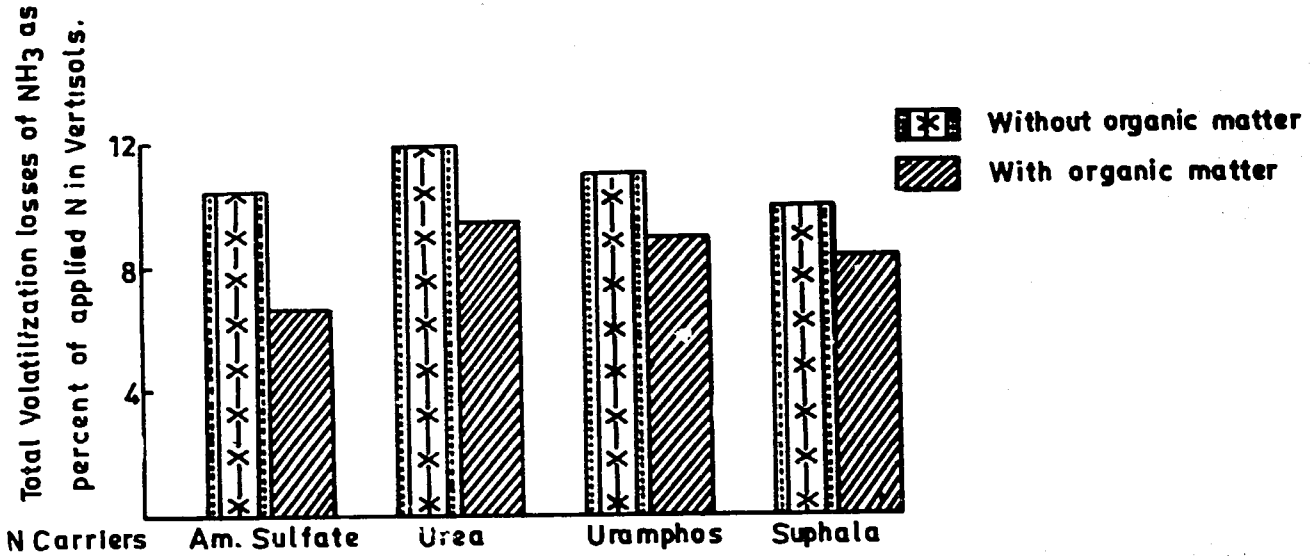

Figure 9a. Volatilization losses of NH_3 as affected by N source and organic matter. (After More et al., 1977.)

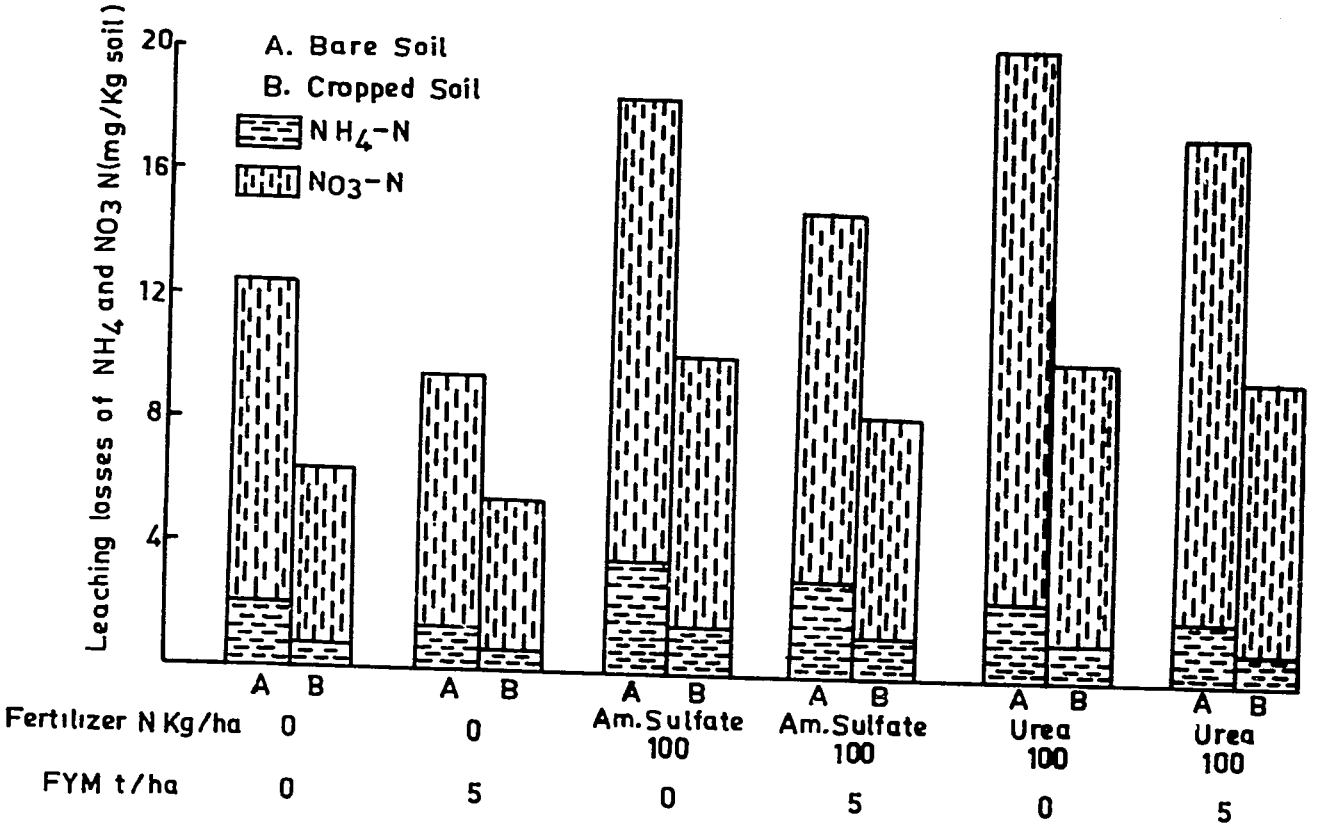

Figure 9b. Leaching losses of NH4 and NO3-N as affected by N source and farm yard manure in Vertisols. (From PAtil and Patil, 1977.)

Balasundaram et al. (1972), in a field experiment with CSH-1 hybrid sorghum as a test cop, reported N requirements of 148 and 59 kg/ha to produce a maximum grain yield of 3.8 t/ha on Vertisols showing soil test N value of 202 and 281 kg/ha respectively (Table 4).

Table 4. Nitrogen requirement for hybrid sorghum in Vertisols under rainfed conditions.[a]

Nutrient	Crop	Soil Test Value	Fertilizer Required	Remarks
		kg/ha		
N	CSH-1	0-202	148	Maximum yield 3.8 t/ha
		203-281	59	
		282-450	-	
		451 and above		

[a]Balasundaram et al (1972).

Phosphorus

Phosphorus availability is probably the greatest constraint to agricultural production in Vertisols. The $NaHCO_3$-soluble P, which is an index of available P, ranges from 2 to 10 ppm and the response to phosphorus was found to vary considerably with a wide variation in phosphorus requirement to reach maximum yields for different crops and locations (Fig. 10; Tables 5 and 6).

Table 5. Grain yield (t/ha) of post-monsoon sorghum in response to P in Vertisols of India under rainfed conditions.

Region	Fertilizer P_2O_5 (kg/ha)						C.D.
	0	40	80	120	160	200	
Bijapur	2.97	3.19	3.42	3.44	3.16	3.12	0.23
Sholapur[a]	0.90	0.75	0.95	0.92	-	-	N.S

[a]Yield values are for 0, 50, 100, and 150 kg P_2O_5/ha.

Source: Venkateswaralu (1979).

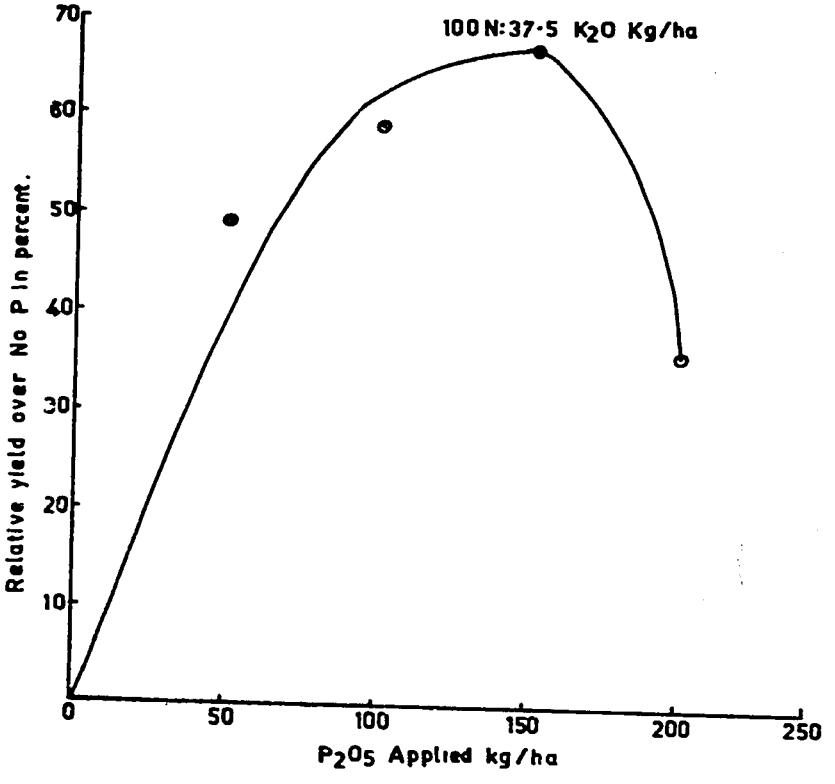

Figure 10. Response of sorghum to fertilizer P in Vertisols (Typic Chromuderts) under irrigation, Dharwad, India. (Source: Ann. Rep. Adv. Centre for Black Soil Res., Dharwad, India, 1978-80.)

Table 6. Response of Rabi jowar SPV-876 and wheat (Bijaga yellow) to applied P in Vertisols under dry land conditions.

P_2O_5 (kg/ha)	SPV 876	Wheat[a]
	(t/ha)	
Control	1.9 (12)	0.67 (11)
12.5	4.2 (20)	1.3 (26)
25	4.2 (28)	1.4 (24)
50	4.9 (31)	1.3 (27)
C.D. (5%)	0.097	0.023

Source: Ann. Rep. of the Advance Centre for Black Soil Research University of Agricultural Sciences, Dharwad Campus, Karnataka, India.

Numbers in parentheses indicate the $NaHCO_3$ (pH 8.5) extractable P in parts per million.

[a]50 kg N was common to all the treatments except control.

A long-term P fertilization experiment with the use of P fertilizers from different carriers was begun in 1978 at the Advance Centre for Black Soil Research, Dharwad, India. This experiment was designed to study the response of legumes to P from different carriers. Phosphorus fertilizers were applied once just before the legumes were seeded. Subsequently, the value of organic residues accumulated as a result of raising legumes. The residual effect of P fertilization by different carriers was tested by growing wheat with only a full dose of N fertilizer and irrigation.

The results shown in Fig. 11 indicate an increase in the yields of legumes and wheat with P application. It was observed that the application of diammonium phosphate outyielded single super and dicalcium phosphates. Further, the data presented in Fig. 11 indicate good residual effects of P fertilization and cowpea in increasing the grain yield of wheat by 33% over that of lucerne and soybean.

The effect of cowpea which received only an initial dose of diammonium phosphate (50 kg/ha) was found to increase the grain yield of wheat by 61% over control and by 6 and 5% over single super and dicalcium phosphates respectively.

Another critical issue for phosphorus management in Vertisols is the source of phosphatic fertilizers. Results of the investigation shown in

Figure 11. Crop yields of legumes and cereals as affected by P sources and legumes in rotation in Vertisols (Typic Chromuderts) under irrigation, Dharwad, India. (Source: Adv. Centre for Black Soil Research Dharwad, Karnataka, India.)

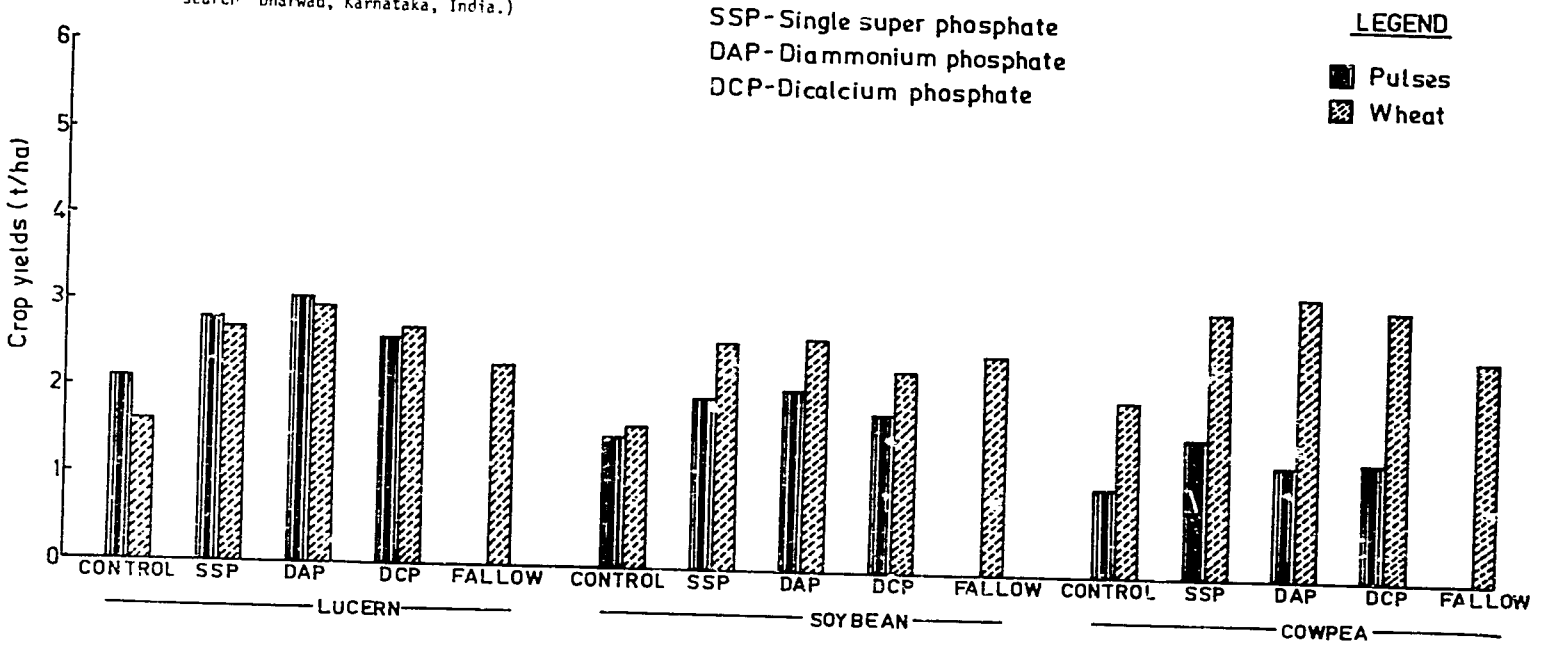

Fig. 11 and that of Dahotonde and Rahate (1977) confirm the importance of the source of P fertilizers. Dahotonde and Rahate (1977) studied the effect of P from nitrophosphate and a mixture of ammonium sulfate and super phosphate on grain yield of maize. The authors found that the response of maize to nitrophosphate was better than to ammonium sulphate and/or a mixture of ammonium sulfate and superphosphate. The results also showed a maximum net profit of Rs. 2,206 from nitrophosphate as compared to Rs. 1,517 from ammonium sulfate and Rs. 2,135 from a mixture of ammonium sulfate and superphosphate (Table 7).

Table 7. Optimum doses and net maximum profit when nitrogen and nitrogen plus phosphate are applied from different sources.

Sources	Optimum dose (kg/ha)	Maximum Net profit
Ammonium sulphate	152 (N)	Rs. 1,517.04
Ammonium sulphate and Super phosphate	158 (N,P_2O_5)	Rs. 2,135.29
Nitrophosphate	160 (N,P_2O_5)	Rs. 2,206.55

Source: Dahatonde and Rahate (1977).

Another important aspect in terms of phosphorus management is the use of organic wastes and recycling of farm residues as a source of nutrients, especially P, for food crops in Vertisols. It has been reported by Allen (1980) that 500 million tons of dung and crop wastes badly needed for improving the soils are being burned by the rural people in the developing countries. It is estimated that in India alone 2.8 million tons of cotton stalks and 11 million tons of maize straw are available and could be profitably used to raise food production. Research conducted at the Advance Centre for Black Soil Research, Dharwad, India, has clearly shown that addition of deoiled neemcake and incorporation of farm residues like cotton and maize stalks increase the $NaHCO_3$-soluble P and DTPA-extractable Mn in Vertisols. Changes in $NaHCO_3$ soluble P and DTPA-extractable Mn are shown in Fig. 12. All of the sources increased the $NaHCO_3$-soluble P and Mn. Further, grain yields of wheat were maximum at P/Mn ratio of one. This emphasizes the balance between P and Mn in Vertisols for higher yields.

Research work reviewed in the foregoing demonstrate that with the use of mixed N and P fertilizers, crop combinations and incorporation of farm residues under irrigation, both native and applied fertilizer P can be efficiently utilized to produce more food in Vertisols that are well known for high sorption and poor response of crops to applied P.

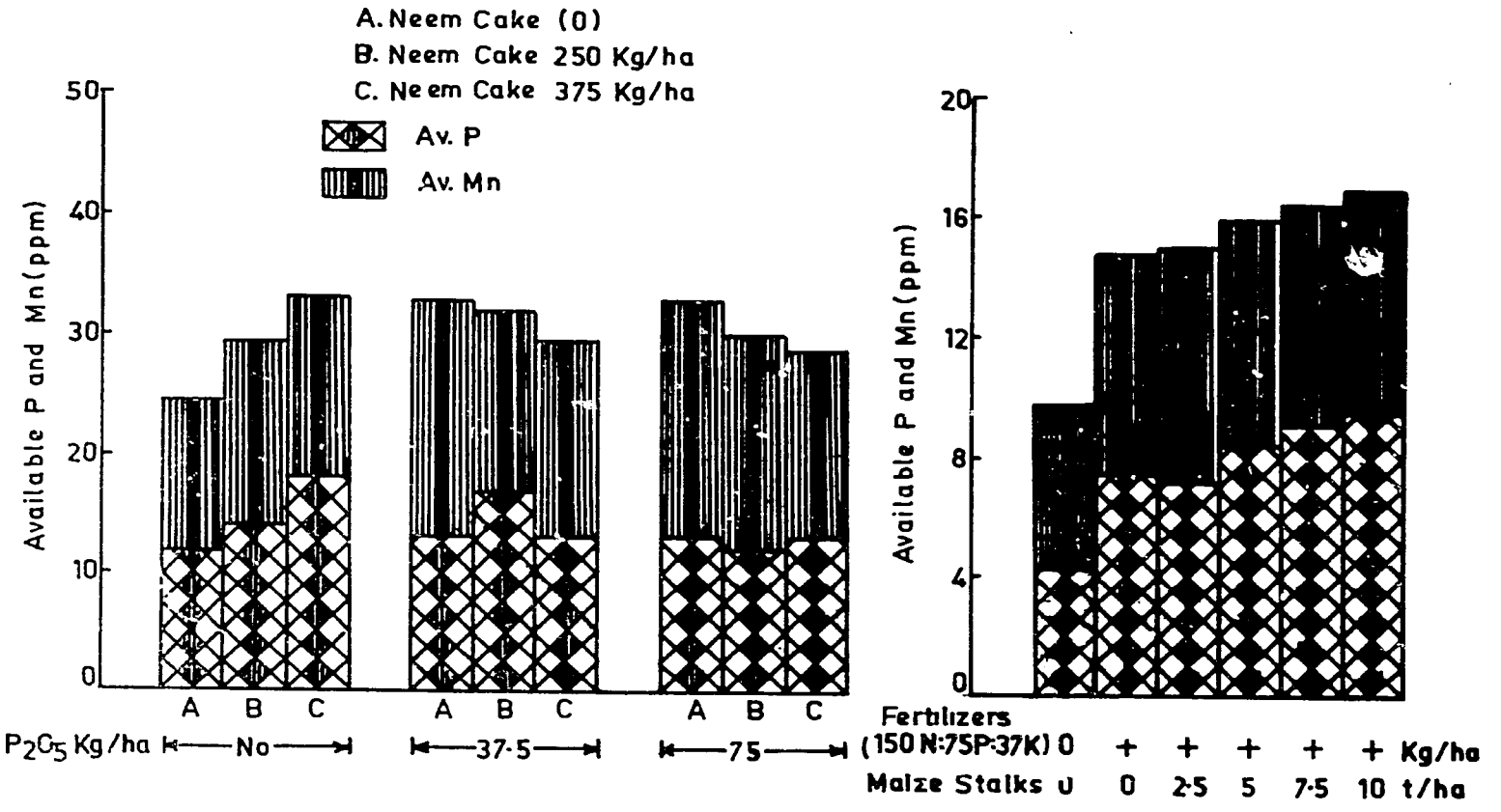

Figure 12. Available P and Mn status as affected by neem cake and maize stalk additions to Vertisols (Typic Chromuderts and Typic Chrousterts) under irrigation. (Source: Ann. Rep. Adv. Centre for Black Soil Res., Dharwad, India, 1978-80.)

Potassium

The total content of K in Vertisols of India is about 1%. The water-soluble K forms a very small fraction of the available potassium. The exchangeable potassium varies from 1 to 4 meq/100 g. Potassium fixation capacity of Vertisols of India ranges from 9 to 32% (Table 8).

Table 8. Potassium fixation capacity of Black soils of India.[a]

State	% K fixed
Andhra Pradesh	9.1
Gujarat	11.0
Karnataka	32.4
Madhya Pradesh	8.0
Maharashtra	7.0
Tamilnadu	4.3

[a]G.K. Zende (1978) Potassium in soils and crops, p. 51-68. Int. Symposium on Potassium, New Delhi.

Unpublished data (Patil and Murthy, 1977) on X-ray diffraction and elemental analyses of soil clays separated from Vertisols of Karnataka indicate that the clays belong to ferriferous-montmorillonite-beidellite series with tetrahedral charge and high charge density. This would contribute to greater fixation of K in Vertisols of Karnataka in contrast to others.

In a laboratory study, potassium chloride was added to the Vertisols and exchangeable potassium level was increased from 0.2 to 15%. This change brought about a marked reduction in soil properties (Table 9) such as plasticity index, swelling behavior, crack width, dispersion, and an increase in hydraulic conductivity. The improvement in the inherent adverse soil properties brought about by the addition of potassium is possibly due to the reduction in electrical double layer repulsive forces resulting from partial conversion of expansible layer silicates to intergrades (unpublished research work of the Advance Centre for Research on Black Soils, Dharwad, India).

Table 9. Physico-chemical properties of Vertisols as modified by potassium chloride treatment.

Exchange-able Potassium % (EPP)	Plastic limit	Liquid limit	Plasti-city index	Dispersion	Free swell	Swelling pressure		Crack width (cm)	Cation exchange capacity (meq/100 g)
	(%)								
0.25	35.1	75.0	39.9	12.9	56.0	0.87[a]	1.20[b]	1 9	74.8
2.05	34.7	69.0	34.3	5.2	47.7	0.73[a]	1.00[b]	1.22	73.8
3.68	33.8	68.0	34.2	1.3	45.5	0.73[a]	0.95[b]	1.00	72.7
13.09	32.4	65.0	32.6	2.0	32.9	0.66[a]	0.80[b]	0.96	68.6
15.15	33.3	66.0	32.7	1.7	33.3	0.72[a]	0.90[b]	0.82	61.4

Source: Unpub. Report of the Advance Centre for Black Soil Res., Dharwad, India.

[a]Under no volume change.

[b]Volume change allowed and recompressed to original volume.

Micronutrients

Vertisols of India in general are fairly rich in total micronutrients, namely iron, manganese, and zinc. Availability of these nutrients are less than 1% of total nutrients. Micronutrient status in Vertisols of Karnataka shown in Figs. 13 and 14 amply demonstrates the above point (unpublished report of the Advance Centre for Black Soil Research). Further, the data shown in Figs. 13 and 14 indicate that the amounts of total and available micronutrients are influenced to a great extent on the nature of the parent material from which the Vertisols are derived. Vertisols of granite-gneiss and calcite origin contain more available Fe, Mn, Cu, and Zn than soils derived from granite and basalt.

Iron and Manganese

Vertisols of India are generally rich in total iron and manganese, having values ranging from 1 to 5%. Availability of iron is low because of high pH, calcareous nature, and high native Mn content.

Iron deficiency in crops grown in Vertisols is a result of the formation of insoluble iron phosphate on the root surface contributing to immobilization of Fe in roots. During the wet phase, when soils are waterlogged either by rainfall or irrigation, iron oxides are mobilized to ferrous iron by bacteria under reducing conditions. The ferrous iron thus formed gets oxidized to Fe^{3+} at the expense of higher valence oxides of Mn and restrict the movement of Fe from roots to other plant parts, resulting in Fe disorder leading to the so-called "iron chlorosis."

This has serious implications in the iron nutrition of crop plants grown in Vertisols with high native manganese. Soil application of fertilizer iron to Vertisols high in native manganese will not be of any benefit and could even aggravate the problem of iron deficiency by bringing more manganese into the soil solution. Unpublished results and the work carried out elsewhere suggests that besides correcting the deficiency through iron-containing fertilizers, the use of genotypes tolerant to iron deficiency has been found to be a promising approach.

Zinc

Total zinc content of Vertisols is on the order of 60 - 90 ppm; that of available zinc is 0.5 ppm.

Results of yield responses of wheat to zinc in Vertisols of Maharashtra and Karnataka are shown in Figs. 15 and 16.

Results from Maharashtra, India, indicate that 20 kg of $ZnSO_4$/ha has increased the grain yield of sonalike wheat by 56% over no zinc treatment (Shinde et al., 1977).

Results similar to this were observed in the experiments conducted by the Advance Centre for Black Soil Research, Dharwad, Karnataka under rainfed conditions. Grain yield of wheat was 1.6 t/ha when the soil was

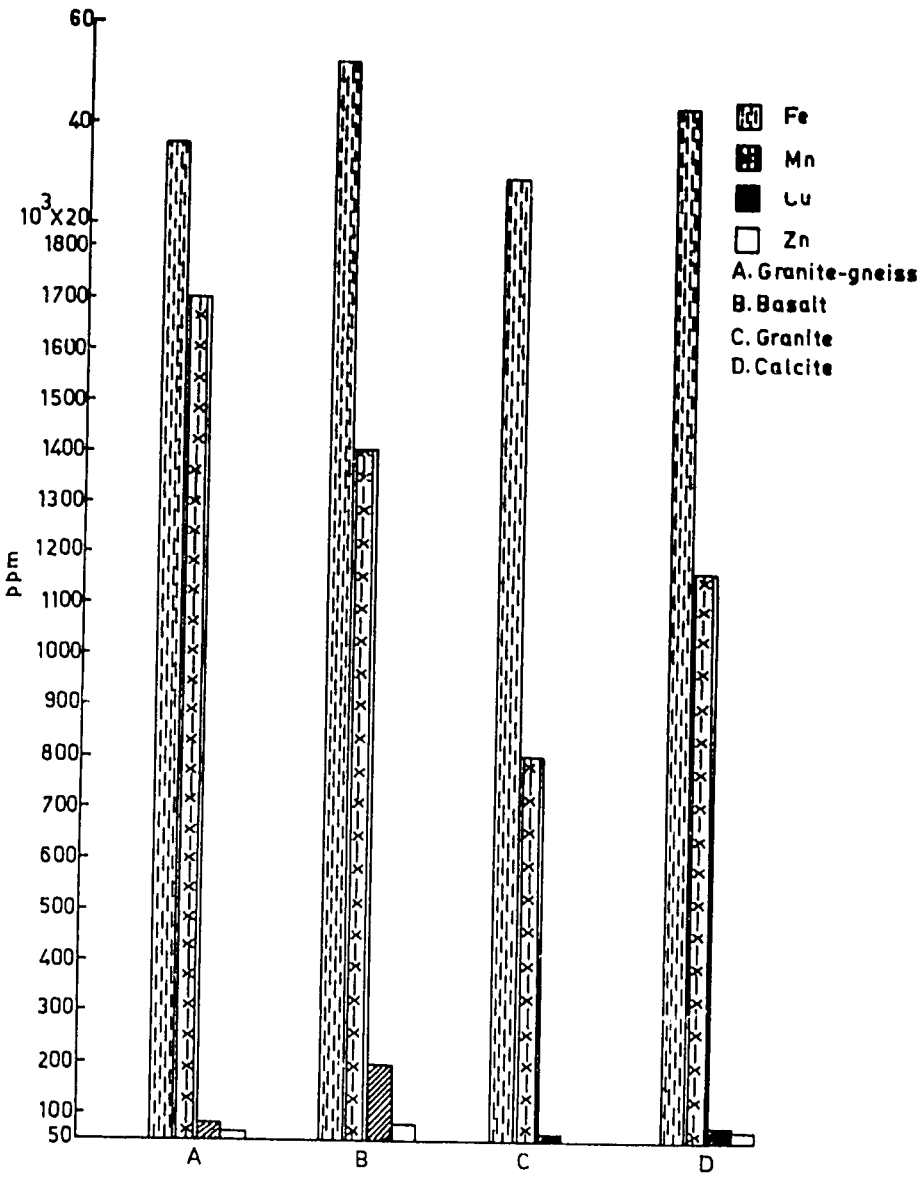

Figure 13. Total micronutrient element status in Vertisols of Karnataka, India. (Source: Ann. Rep. Adv. Centre for Black Soil Res., Dharwad, India, 1980-81.)

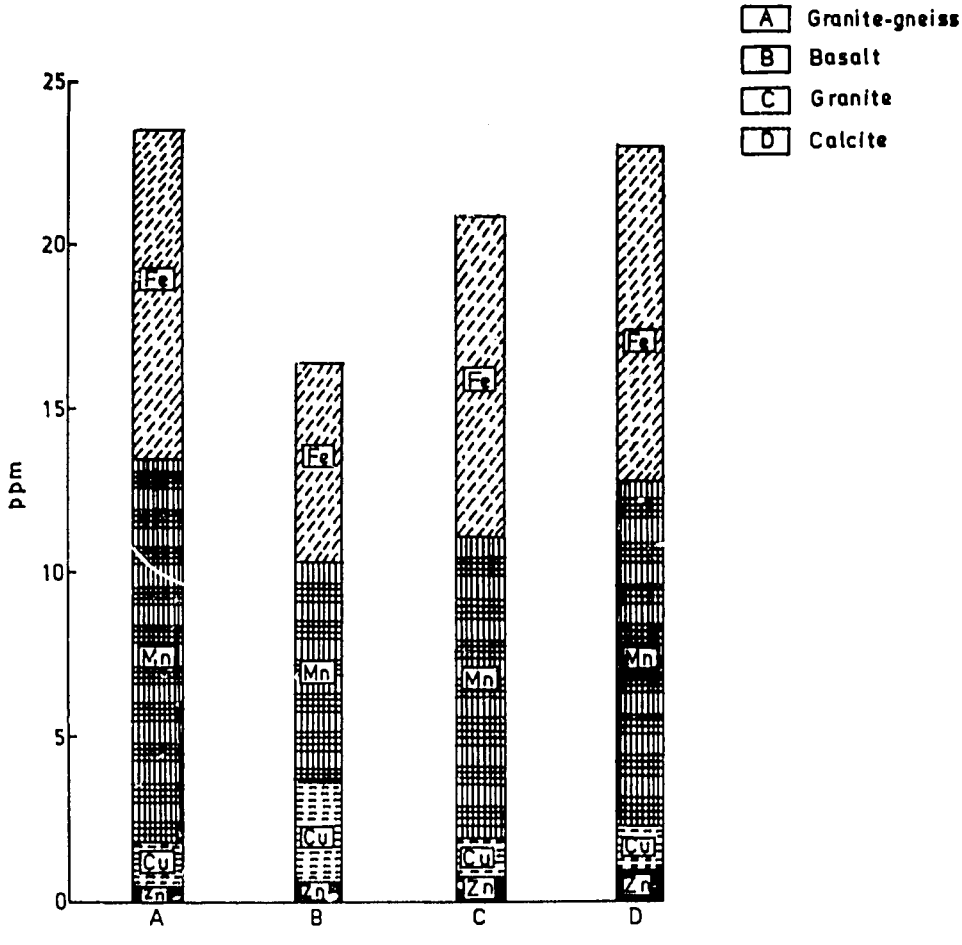

Figure 14. Available micronutrient element status in Vertisols of Karnataka, India. (Source: Ann. Rep. Adv. Centre for Black Soil Res., Dharwad, India, 1980-81.)

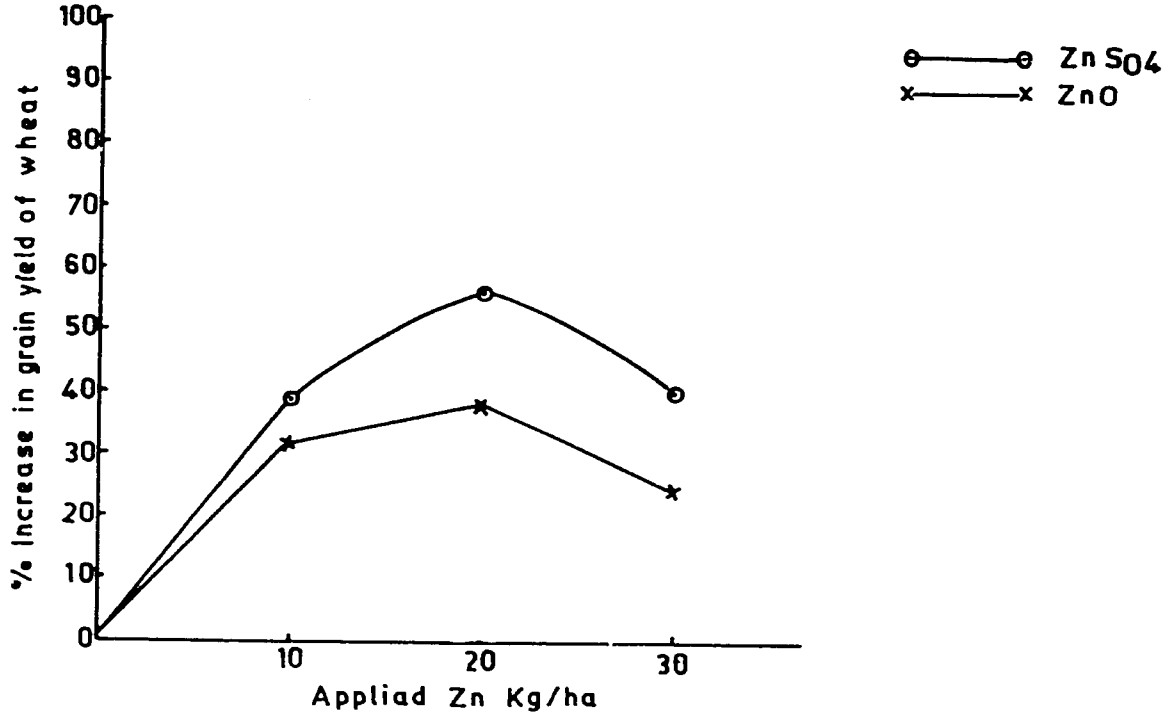

Figure 15. Wheat grain yield as influenced by the application of graded levels of zinc through two sources. (After Shinde et al., 1977.)

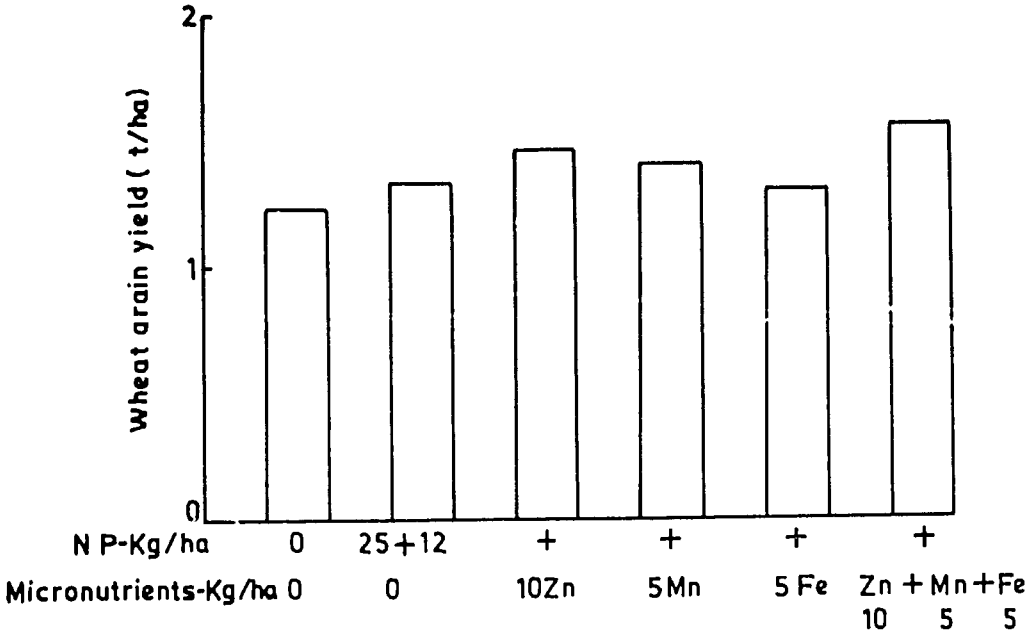

Figure 16. Response of wheat to micronutrients in Vertisols (Typic Chromusterts) under dryland conditions. (Source: Ann. Rep. Adv. Centre for Black Soil Res., Dharwad, India, 1981-82.)

supplied with 25 N and 12.5 kg P_2O_5 per ha along with Zn, Mn, and Fe as compared with 1.3 t/ha under 25 N and 12.5 kg P_2O_5 only (Fig. 16). This indicates that the response of wheat to micronutrients will be better when the crop is provided with a mixture of Zn, Mn, and Fe.

Copper

The total copper content of Vertisols of India is 100 ppm. Available copper as measured by DTPA extraction is in the range of 1 - 2 ppm. Vertisols are not copper deficient, and hardly any positive yield response to copper has been reported.

Molybdenum

Total molybdenum content of Vertisols is in the range of 1 - 3 ppm. There has not been much research on the response of crops to molybdenum in Vertisols of India.

Unpublished research work of the Advance Centre for Black Soil Research indicate a significant response of cowpea to applied molybdenum in irrigated Vertisols of Karnataka (Fig. 17). Direct application of molybdenum to cowpea at the rate of 0.5 kg per ha with 10N, 50 P_2O_5, 10 K_2O kg/ha showed an increase in grain yield by 0.27 t/ha over no fertilizers. Further, the data presented in Fig. 17 indicate a good residual affect of molybdenum on the post-monsoon sorghum crop.

ACKNOWLEDGEMENT

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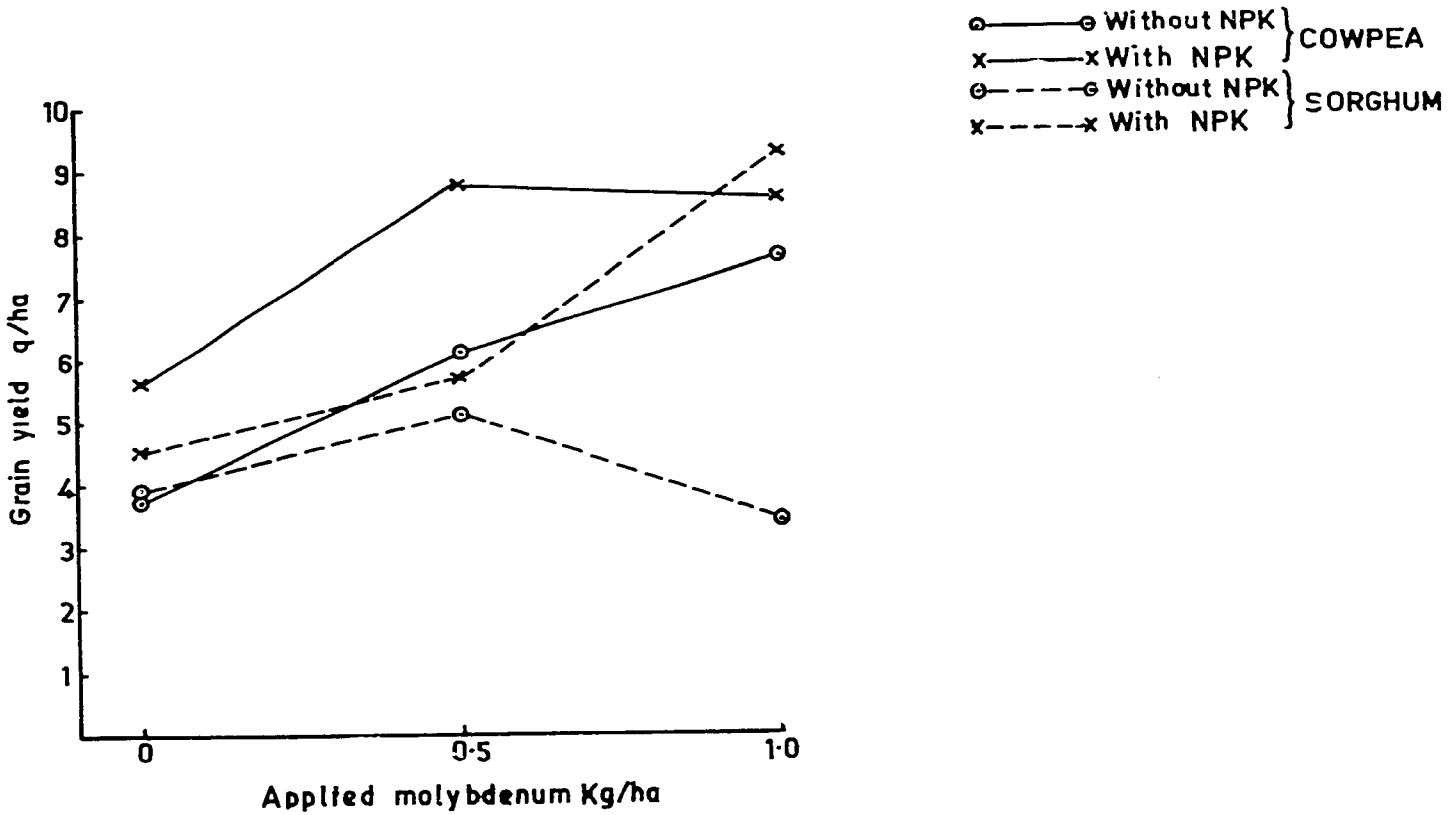

Figure 17. Response of cowpea to added molybdenum and its residual effect on postmonsoon sorghum crop. (Source: Ann. Rep. Adv. Centre for Black Soil Res., Dharwad, India, 1979-81.)

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MANAGEMENT OF VERTISOLS FOR RAINFED CROP PRODUCTION IN THE SUDAN

M.A. Mahmoud

Of the total crop area of the Sudan, nearly 85% is rainfed. This percentage is increasing due to the rapid expansion in rainfed mechanized farming as compared to the limited expansion possible in irrigated areas. The Sudan has a reserve of some 75 million hectares of arable land still untapped. With the limitations we have in available and potential irrigation water, almost all these reserves seem to be destined for rainfed cropping, if and when they are brought under cultivation.

About 6.5 million hectares are being cropped annually in the rainlands. This is divided almost equally between two sectors: the so-called "traditional" and "modern" sectors.

The traditional sector refers to the peasant farming methods--cultivating a few hectares per family using primitive hand tools--which has existed in the country for millenia. It also includes the now almost vanished "hareeg" cultivation. Until the advent of the tractor, hareeg was the only means for cropping a comparatively larger area than hand tools would allow. Essentially it consists of leaving the land to rest for two or more years to develop a dense cover of tall grasses, well protected by fire lines. After enough rains have fallen to germinate the week seeds, this cover of dry grasses is set afire (hence the name "hareeg") to destroy the new weed seedlings. As a result, the farmer is relieved of much of the tedious hand-weeding which limited the land he could have cultivated using a hoe. In many ways, the disappearance of hareeg is to be lamented.

By "modern" sector we mean that type of rainfed farming where at least a tractor and harrow are used for preparing a clean seedbed. Almost invariably this is followed by mechanical seeding with a seed drill or a combined disc harrow/seeder. In most cases harvesting is still done by hand, but a combine is used for threshing sorghum.

The Vertisols present no serious management problems for the traditional farmer. The difficulty of working these soils with a hand hoe and the hazard of their getting waterlogged are perhaps the only management aspects worthy of mention. Hence, we are here dealing mainly with management of the Vertisols under mechanized farming.

RAINFALL

Rainfed mechanized farming is mostly practiced in areas with an annual rainfall of 500 mm and more. The greatest bulk of its area lies between the 600 mm and 800 mm isohytes on the heavy cracking clays of the Central Rainlands belt. No mechanization to speak of is practiced on light soils in this belt or elsewhere in the country.

Table 1 gives the long-term (30-35 years) average monthly and annual rainfall of five stations that represent the major centers of mechanized farming. From this table it is evident that summer is the rainy season in these areas. Though there are some showers in April and May, effective rains start in June. They reach their peak in August, or sometimes in July, and end, almost abruptly, in October. This pattern is true for potential areas of mechanized farming expansion on the clay plains, though the season lengthens at both ends as one goes south, with increased monthly and annual totals.

Table 1. Total monthly and annual rainfall (mm), at five stations in main mechanized farming centers (average of 30-35 years).

Station	January	February	March	April	May	June	July	August	September	October	November	December	Total
Gedaref	0	0	0	4	27	83	157	187	99	23	3	0	584
Doka	0	0	1	6	31	121	186	196	108	37	4	0	680
Roseisis	0	0	1	19	40	119	181	203	129	41	3	0	736
Renk	0	0	1	3	28	74	117	155	95	54	1	0	528
Dilling	0	0	2	6	40	83	147	171	111	46	1	0	606

CROPS

The present main crops of both sectors of the rainfed Vertisols are sorghum, sesame, and cotton. Efforts are being made to introduce new crops, especially soybean and sunflower, to achieve higher and more stable profits and to maintain soil fertility and health through more balanced crop rotations. Maize grows and yields well in these environments, but farmers have not developed any interest in it.

Sorghum

Sorghum occupies around 40% of the country's total cropped area, and about 85-90% of the mechanized rainfed sector. Its wide range of adaptation, ease of mechanization, and low cost of production accounts for this high percentage under mechanization. This is not agronomically desirable, as it results in virtual monocropping with a soil-depleting crop associated with the noxious, parasitic weed "buda" (*Striga hermonthica*).

Sesame

Sesame accounts for about 1 million hectares, or 15% of Sudan's cropped area. Of the total sesame area, 42% is on Vertisols and 22% is in the mechanized sector. The crop is wholly rainfed in this country. It is sensitive to the excessive moisture apt to be encountered on clays. On such heavy soils, the crop failed to respond to applications of major fertilizers, and it was found to be the best precursor to all crops in crop sequence trials. In spite of this, the share it occupies in rotations is limited due to the shattering nature of its mature capsules. This calls for intensive labor within a short period for harvest and has up to now ruled out mechanical harvesting.

The difficulty of preparing a fine seedbed on rainfed heavy clays presents some problems with the placement of sesame's minute seeds at sowing and with the emergence of its weak seedlings.

Cotton

A small area of cotton is grown in the mechanized sector, not exceeding 1% of its total cropped area. The soils present no special problems for cotton growing, but in most of the area, the rainy season is usually too short for a good crop of cotton. The crop's area is expected to increase as mechanization advances towards regions of higher rainfall.

In all fertilizer trials with cotton in the rainlands, there were no favorable yield responses. Yields were occasionally depressed by nitrogen application, contrary to experience with irrigated cotton. This behavior is most probably due to a delay in flowering and enhancement of vegetative growth caused by nitrogen. Both effects are hazardous under such a short season.

MANAGEMENT PROBLEMS OF MECHANIZED RAINFED VERTISOLS

Soil, moisture, machinery, and crops interact to create different problems which have to be well understood. Such an understanding is essential for good management and profitable farming. Many of these problems have yet to be investigated by researchers to arrive at solutions. The main problems caused by each of the major factors are briefly outlined here.

Soils

When dry, Vertisols contract, harden, and crack heavily. Very powerful and expensive tractors and tillage implements are needed to work them in the period January to May. Tractors and implements now commonly in use cannot work the soil during this period. Early harvest makes it possible to carry some of the primary tillage immediately after harvest while the soils are still workable. This also makes it possible to start secondary tillage and sowing early after the onset of rains.

Post-harvest tillage would give the soil adequate time to dry, forming the cracks so beneficial for deep penetration of rainwater. Pre-sowing heavy tillage tends to seal these cracks, causing waterlogging and runoff.

On the other hand, these soils are so sticky when wet that machinery cannot be used. Tractors get stuck, and harrows, planters, and seed drills get clogged. Preparation of a good seedbed and proper placement of seed become difficult or impossible on soils that are too wet. The number of days that machinery can be used in the field decrease with increasing rains, thus going from 15 to 18 days in June to 3 to 5 days in August.

To overcome these difficulties, it is recommended to start land preparation and sowing as early as made possible by the onset of rains. For best results, sowing should end by mid-July. To help achieve this end, the use of herbicides is being investigated and promoted. Most farmers delay their sowing awaiting maximum weed germination, so as to destroy these weeds with the last harrowing. Successful use of herbicides would obviate the need for this delay. Delayed sowing is perhaps the major reason for the low yields now obtained.

Low permeability is another feature of these soils. At the peak of rains this results in loss of valuable water through evaporation and runoff. This is often associated with harmful waterlogging.

Use of chisel ploughs and incorporation of crop residues are some of the remedies recommended (and debated) to promote permeability. Research has yet to prove their value and solve problems facing their application. Early sowing, however, is again recommended to minimize the harmful effects of waterlogging as older plants are more tolerant.

Moisture

What was said about soils says much about moisture. However, though the soils are practically uniform throughout the mechanized area, moisture is not. In the northern limits much yield is lost due to moisture deficiency, while in its extreme south excessive moisture may cause as great or even greater losses. Growing of crops and varieties of the appropriate maturity period and drought or waterlogging tolerance is the main recommendation here. Methods to promote moisture conservation or excess water drainage are to be used. Crop densities are to be adjusted for optimum use of available moisture.

An important management aspect in the clay rainlands is provision of water for human and animal use and crop spraying. Most of these lands lacks

any form of tapable groundwater. Ponded rainwater is the only source. Artificial ponds (the so-called "hafirs") are an essential part of farming in these area. The low permeability of the soil is an asset for this method of water storage.

Machinery

Much debate is going on about the best kind and size of tractor and implements to use, and what operations are most beneficial or least harmful. The debate covers such matters as soil compaction and hardpanning, minimum tillage, destruction of weeds, moisture preservation, fate of crop residues, maximization of yields, and reduction of costs of production and soil conservation. Researchers are just starting to investigate these questions and much has to await their findings.

At present, most farmers use a medium-size tractor of 65-75 HP and a wide-level disc harrow/seeder. The land is harrowed once, or sometimes twice, before sowing and once again with sowing. The seeder is used in such a way that the seed is almost broadcast rather than drilled. Weeding is done by hand. Except for threshing sorghum, all harvesting operations are manual.

GROUNDNUT PRODUCTION IN IRRIGATED VERTISOLS OF THE GEZIRA: ACHIEVEMENTS AND PROBLEMS

H.M. Ishag and M.B. Said

Groundnuts (*Arachis hypogaea* L.) are a valuable cash and export crop for the Sudan, ranking third in 1971. In 1980, there was a decline in exported tonnage (22,000 tons) and groundnuts ranked fifth and contributed 2.2% of the total export value (Anon., 1980).

Groundnuts have become increasingly important in irrigated areas of the Sudan. Seventeen to 25% of the total acreage is under irrigation, and this produces about 75% of the total production. The acreage under irrigation provides a stabilizing effect on groundnut production, which is not present in other groundnut-producing areas of the world.

Up to the 1960s there was an erroneous belief that the heavy clay soils of the Gezira were not suited for groundnut production. Pursuant to this belief, a minimum research effort was carried out in the Agricultural Research Corporation on this crop. In 1946 the British government proposed a bold plan to grow 3.21 million acres of groundnuts using mechanical production in East Africa in order to alleviate the world's chronic shortage of facts (Matheson and Bovill, 1950).

Detailed and intensive research showed that the potential and pod yield of groundnuts in irrigated Gezira is about 6.7 tons per hectare (Ishag, 1982a). The main factors contributing to this high yield are: climate, soils and fertilizers, and crop management.

CLIMATE

Groundnuts are grown from 40° N to 40°S of the equator. The climate of the Gezira is semi-arid with abundant sunshine and a solar radiation of 548 cal/cm^2/day. McKinion et al. (1974) reported that groundnuts are more efficient in light capture than cotton. The rainy season is from May to October with the heaviest rainfall during July and August. High relative humidity in July-August promotes flower production. Average temperatures vary from 33°C in May to 23°C in January. The absolute maximum is around 45°C and the minimum is around 15°C (AOAD, 1974). Incidence of diseases is little in the Gezira environment owing to the warm subtropical climate. Thus, the Gezira climate does not impose limitations for groundnut production.

SOILS AND FERTILIZERS

Soils

The Gezira is that part of the central clay plain of the Sudan situated between the Blue and White Nile Rivers south of Khartoum. The Gezira scheme and the Managil extension which are watered from the Blue Nile occupy the northern part of the central clay plain; this is the most important agricultural land in the Sudan. The general assessment of heavy clay soils in the central clay plain from the point of view of suitability for irrigation rests on a foundation laid in work in the Gezira soils.

The soils of the Gezira are relatively uniform due to uniform parent material, nearly level relief and hot semiarid climate. Several attempts were made in the past to identify and classify the Gezira soils. Finck (1961) reviewed all these past attempts and proposed that the Gezira soils are mostly Vertisols. Finck's proposal was further extended to classify and define approximately the extent of the various subgroups and types identified in the Gezira area (Robinson, Magar and Rai, 1969). York and Colwell (1951) described the ideal soil for groundnuts as a "well-drained, light-colored, friable, sandy loam, well supplied with calcium and moderate amounts of organic matter". Reid and Cox (1973) considered other soil properties which affect the growth and yield of groundnuts, namely the influence of soil properties on air, water, temperature, pest and ease of cultivation, digging, and harvesting.

The Gezira soil is alkaline, high in cracking montmorillonitic clay with impeded drainage and a high salt content. The water table is some 60 feet below the surface water table. In general, the clay content increases from north to south over the Gezira plain and is usually uniform with depth or increases slightly. Although relatively high in nutrient content, productivity may be limited because of difficulties in management. The high clay content tends to stain the pods of groundnuts as the clay particles adhere to them. With regard to soil reaction, the optimum pH for groundnuts varies from 5.5 to 6.2, but high pod yield is obtained with higher pH.

Groundnuts perform rather poorly in sodic soils because higher exchangeable sodium percentage antagonizes the absorption of calcium, an important nutrient element for pod filling.

Groundnuts are a soil-depleting crop and require a considerable amount of nutrients for high yields. Martin (1965) reported that for every ton of unshelled pods and one ton of hay, 40-47 kg of N, 7.5-8 kg of P_2O_5, 16-22 of K_2O, 9-14 kg of CaO and 10-12 kg of MgO are removed.

Nitrogen

Vertisols of the Gezira are inherently low in nitrogen; urea is commonly used to supply extra nitrogen for most of the crops grown in the rotation. This low content of nitrogen (300 ppm) is expected because of the prevailing climatic conditions. However, groundnuts' response to nitrogen fertilization

of urea at the rate of 40 kg N/ha did not increase the pod yield of semi-spreading types. On the other hand, Hadad (1981) reported an increase in pods when applying 40 kg N/ha to Barberton (a bunch type) probably because of the different growth habit of the root system. It is noteworthy that the utilization of applied nitrogen in these alkaline heavy clay soils is relatively low. This low recovery is attributed mainly to volatilization of ammonia and to a lesser extent to leaching and ammonium fixation (Jewitt, 1942; Musa, 1968; Said, 1973).

Nodulation is generally satisfactory and groundnuts grown at the Gezira Research Station were found to fix 100 kg N/ha (Musa, 1974). Inoculation of Ashford variety increased pod yield by only 4%.

Phosphorus

The total phosphorus values of the Gezira Vertisols are generally high throughout the profile, varying between 406 and 700 ppm and the values, generally, increased from north to south (Said, 1975). Available phosphorus, estimated by the sodium bicarbonate extraction procedure, was very low (1.4 to 4.5 ppm). Results from studies on the fate of fertilizer phosphorus added to these soils indicated that most of the applied phosphorus was converted to calcium phosphate and retained in the top 30 cm layer. In conformity with this finding, Ishag et al. (1980) found that broadcasting fertilizer phosphorus had no effect on groundnuts' yield, but applying the fertilizer with the seed gave an increase in yield up to 21%. Significant response to placed phosphorus is expected when the high phosphorus requirement of the leguminous crop and the very low values of available phosphorus are taken into consideration. Nodulation of legumes was reported to be checked by phosphorus deficiency while added phosphorus was found to increase the number and density of nodules, nodule growth, the rate of nitrogen fixation per weight and the uptake of other nutrients, probably as a result of increased root activity (De Geus, 1967).

Other nutrients

With regard to other macro- and micronutrients, the Gezira Vertisols are rich in potassium, calcium, sulphur, and probably also in magnesium (Finck and Peters, 1961). Micronutrients received little attention but it is generally considered that manganese, copper, boron, and molybdenum are in adequate supply. Zinc deficiency was reported in citrus trees and maize. The first micronutrient deficiency detected in the Gezira Vertisols was an iron chlorosis of groundnuts (Finck, 1960). The effect of this chlorosis on final yield was investigated by Babiker (1963).

CROP MANAGEMENT

Rotation

The present Gezira rotation is cotton-wheat-groundnut/dura-fallow, and

before that it was cotton-groundnut/dura-wheat-fallow. Because of the short period between the pulling of cotton stalks and land preparation and planting of groundnuts, the rotation was changed to the present one. In Managil, the rotation is cotton-wheat-groundnut/dura with no fallow. In Suki and Rahad, a two-course rotation, cotton-groundnuts, is adopted. In closer rotation, yields of crops, such as cotton and groundnuts, are expected to decrease year after year due to loss in soil fertility.

Land preparation

Groundnuts require a loose, friable soil into which the pegs can penetrate easily. The highest pod yield of groundnuts was obtained when the land was disc-ploughed at a depth of 20 cm followed by harrowing or disc-ploughing at the same depth followed by rotovation (Ishag et al., 1980). Under heavy rainfall conditions, the introduction of rotovation gave higher pod yield than harrowing, probably because it had created good crumbly, receptive surface that trapped most of the rains in the root zone.

Ridging only, which is the common practice for groundnut production in irrigated schemes, consistently gave lower pod yield. Ridging only was expected to have resulted in unfavorable soil physical conditions, i.e. compactedsubsurface layer, restricted root growth and development, and restricted free movement of water and soil aeration. These conditions may have contributed to the formation of fewer pods per plant. To obtain high pod yield under such conditions, closer spacing must be adopted. However, when disc-ploughing with harrowing or rotovation is practiced, a lower seed rate can be used because of the production of more numbers of branches and more numbers of pods per plant.

Sowing date

Early sowings increase both pod and hay yield. Yields in the Gezira were found to decrease 53% from June to September sowings. For Virginia type, the reduction in yield was 53%, while for Spanish type, the reduction in yield was even higher, amounting to 70% (Ishag, 1965).

Plant population

One of the most critical factors limiting yields of groundnuts is low plant population. In the Gezira Research Station, the highest yield of Ashford variety was obtained at 60 cm x 15 cm spacing while the highest yield of Barberton (Spanish type) was obtained at 40 cm x 15 cm. It is suggested that the optimum spacing for these varieties varied because of differences in their growth habits (Ishag, 1970).

Cultivars

MH 383 cultivar outyielded all other cultivars in all seasons and in different sites. Ishag (1982) reported that MH 383 exhibited drought tolerance. Spanish types, which are normally grown in rainfed areas of western Sudan, yield less in the Gezira than the semi-spreading cultivars because

of smaller sink size. Newly introduced cultivars from the USA, i.e. NC 17, Florigiant and Florunner, proved to be lower yielders for the Gezira environment. They are poorly nodulated, sensitive to delay in sowing, and highly susceptible to termite damage. Suitable groundnut genotypes are needed to suit Gezira soils.

Weed control

Weeds reduce the pod yield of groundnuts by about 80% (Ishag, 1971).

The following pre-emergency herbicides were found to be effective in controlling weeds in groundnuts: Ronstar (Oxadiazon) at a rate of 0.45-0.60 kg a.i. per feddan; Balan (Benefin) at a rate of 0.60 kg a.i. per feddan, and Tok E-25 (Nitrofen) at a rate of 1.50-2.00 kg a.i. per feddan. Low rates of herbicides are sufficient to control weeds under the heavy clay soils, mainly because of low organic matter, high pH, and low permeability (Babiker, 1979). The high soil and air temperature also favor rapid uptake of herbicides.

Irrigation

Total water requirement for groundnuts in the irrigated Gezira was found to be 450-500 mm (Fadl, 1977).

Too frequent irrigation decreases pod yield. Watering a montmorillonitic clay results in swelling and consequently poor soil aeration. The resulting shortage in oxygen supply to the roots causes nutritional deficiency even if the soil is adequately supplied with available nutrients (Finck and Karouri, 1964).

Since groundnuts are planted during the rainy season, additional irrigation should be carried out very cautiously.

Harvesting

The time of harvesting is critical, as it affects both yield and quality of nuts. Too early harvesting causes the shrivelling of kernels. Lifting groundnuts late results in higher pod losses (68%). These losses are mainly due to disintegration of hynopheres by the wetting and drying process, (Ishag, 1977). Late harvest also subjects the pods to termite damage which encourages aflatoxin contamination.

Hand harvest is hard work even when a predigging irrigation is used to soften the soil. Mechanization of the lifting process is possible, but most of the machinery developed for groundnuts in other countries was designed for light, sandy soils. Groundnut pickers can be used to harvest the pods. The vines can then be gathered and used for cattle feed.

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PROPERTIES AND MANAGEMENT OF ARIDISOLS

- A GENERAL APPRAISAL -

H. Lüken and F. Grüneberg

ABSTRACT

Aridisols are dry for more than half the time, or never continuously moist for more than 90 days. The aridic soil moisture regime determines the mode of formation of the soil, its properties and the management requirements for different soil uses.

The soil profile was taken as the starting point in the discussion of diagnostic criteria, based mainly on the subsoil, for proper management of Aridisols. Argillic horizons can be formed subsequently to carbonate removal, but this is unlikely under arid climatic conditions, where percolation of moisture through the profile is restricted to a few rainfall events during the year or to particular topographic locations. Any argillic horizons present in soils in arid regions were most probably formed in the past under more humid paleoclimatic conditions. They can be a favorable attribute to soil quality with respect to moisture-holding capacity. But the textural heterogeneity may also be disadvantageous, interrupting the continuity of soil pores and thus restricting water movement. Under an average negative balance, duric, natric, salic, calcic, or gypsic horizons may be formed which in the case of hardened, compact layers interfere with root penetration, or in case of salt accumulations with plant nutrition.

Leaching procedures are successful only if salts are leached to sufficient depth and if a net percolation is maintained during crop periods. Alkalinization occurs in cases where this is not adequately carried out. When comparing soil quality requirements for agricultural production, rainfed agriculture may be more sensitive to adverse soil conditions than irrigated agriculture. With irrigation, some deficiencies of soil quality may be compensated through irrigation management. Soil conservation is gaining in importance where natural conditions are increasingly adverse. An equilibrium has to be maintained between land resource capacity and land resource utilization. Afforestation has become especially important for land protection.

INTRODUCTION

The term "Aridisol" stems from the U.S. Soil Taxonomy (Soil Survey Staff, 1975) and refers to soils of the aridic climatic zone. A few Aridisols

occur in semi-arid regions and are dry because of lack of sufficient water penetration and consequent high rates of rainfall runoff. Aridisols do not support the growth of higher plants except drought-resistant succulents and xerophytic or short-lived species.

Pedologically Aridisols are characterized by the accumulation of salts and carbonates. Stone layers are often found at the surface, the so-called "desert pavement."

CHARACTERIZATION OF ARIDISOLS

Aridisols are distributed throughout the aridic climatic zones. In Soil Taxonomy (Soil Survey Staff, 1975) Aridisols are a separate order represented at the highest classification level. They are defined according to soil moisture regime (SMR) and soil temperature regime (STR) among other criteria. Both SMR and STR are closely related to the respective climatical parameter, but not necessarily identical. The water, which moistens the soil, can also originate from sources other than rainfall, such as runoff-water, groundwater, or stored soil water.

The extent of climatically arid regions is not the same as the extent of Aridisols, as can clearly be seen in Fig. 1. The climatic delimitations are drawn according to Köppen (1931). The dry areas, the so-called "B" climatic zones composed of desert ("BW") and steppe ("BS") regions, are differentiated from more humid regions. The main criteria for the dry regions is that the annual evaporation is greater than the annual precipitation. The delimitation of Aridisols in Fig. 1 is in accordance with "Soils of the World," U.S. Department of Agriculture, Soil Conservation Service (1972).

According to Dregne (1976), arid-region soils account for 31.5% of the world land area, and Aridisols, in the strict sense, for 11.3%. The difference between these figures, roughly 20%, is accounted for, e.g., by barren lands and wind-blown sand dunes, which are of little agricultural importance. Soils from these regions do not comply with the diagnostic criteria of Aridisols. They are generally classified as Entisols.

The position of Aridisols in relation to other orders can be derived from Fig. 2. The orders are drawn within a thermopluvial coordinate system. They are arranged according to their spread over the respective soil moisture regimes (SMR) and soil temperature regimes (STR) and to their zonality. It is apparent that Aridisols are restricted to the aridic/torric SMR only, and to warm or warmer than frigid STR. Only intergrades of Aridisols, which are not included in Fig. 2, can have a xeric or an ustic SMR. They appear in a lower classification category, the subgroup.

The restriction of Aridisols to the aridic SMR at the higher classification categories (order, suborder, and great group) requires that, according to the Soil Taxonomy definitions, the moisture control section of the Aridisols be dry in all parts for more than half the time (cumulative) or never moist in some or all parts for more than 90 continuous days. The first condition applies to Aridisols under frigid but warmer than 5°C

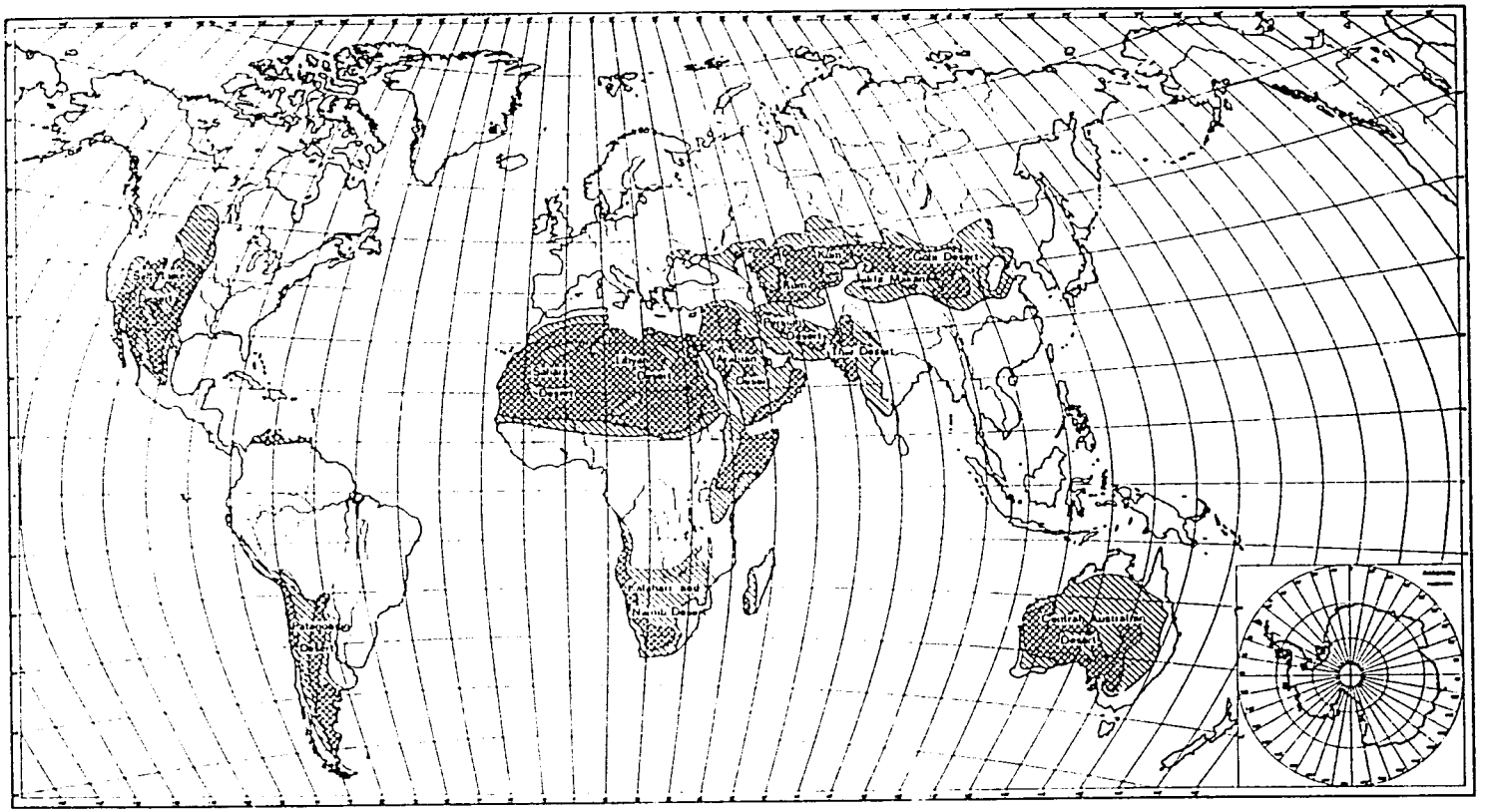


Fig. 1: Global distribution of dry climates and the occurrence of Aridisols

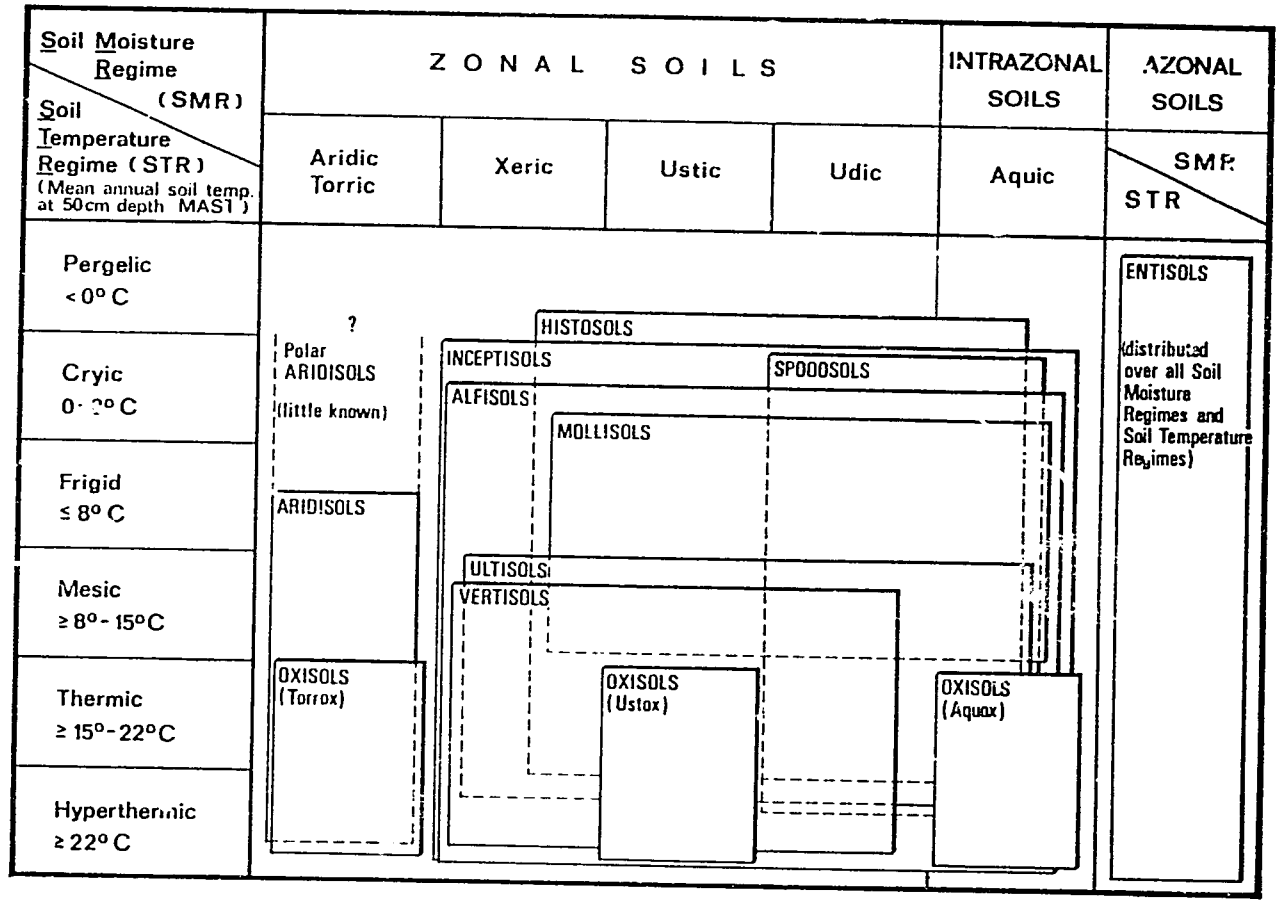


Fig. 2: Distribution of soil orders within the thermo-pluvial co-ordinate system of Soil Taxonomy

mean annual soil temperature (MAST) conditions at 50 cm soil depth. The second condition applies to soils with mesic or warmer MAST values. Since available water for plant growth is extremely low under those conditions, it means that Typic Aridisols (central concept according to Soil Taxonomy) are not suitable for general arable farming unless irrigated.

With regard to STR, polar Aridisols have so far been excluded from the classification according to Soil Taxonomy, because knowledge concerning these areas is still scarce, and because they are without agricultural significance. According to Claridge and Campbell (1982), however, similarities exist between hot and cold desert soils.

When going into other internationally used classification systems, terminology and meaning of arid-region soils are not uniform. This is partly due to differences in the definition of aridic (climatical or pedological), and to differences in categorical subordination.

FAO/UNESCO (1974) distinguishes Yermosols from Xerosols at the highest category, though both orders have an aridic (climatic) moisture regime. Furthermore, in the FAO system Solonchaks and Solonetz soils are separated as individual units at the highest classification level, whereas Soil Taxonomy includes them under Aridisols at the great group level. This can be important in the weighing of soil characcteristics with respect to agricultural land use, as described, for example, by Vogg (1981) for Sahara desert soils.

ENVIRONMENTAL FACTORS OF ARIDISOLS

Parent material and environmental factors, leading to certain developmental processes of the soil and the landscape, influence the properties of Aridisols. In accordance with the soil-forming factors as defined by Jenny (1941), we must differentiate between climate, organisms, topography, parent material, and time.

Climate

The arid climate is, as shown in Fig. 2, the dominating soil-forming factor. It is also the dominating ecological factor, and is very restrictive to plant production.

In Fig. 3, the climatic data of the aridic zone are related to the soil water balance (Fig. 3, according to Soil Survey Staff, 1975). The graph presents three parameters: precipitation, potential evapotranspiration (PE) estimated according to the Thornthwaite formula, and air temperature. The areas delimited by the precipitation and evapotranspiration lines in Fig. 3 indicate three important moisture characteristics:

R = period of recharge, where precipitation exceeds evapotranspiration;

U = period of water utilization, where plant-available soil water is present (<15 bar suction pressure); and

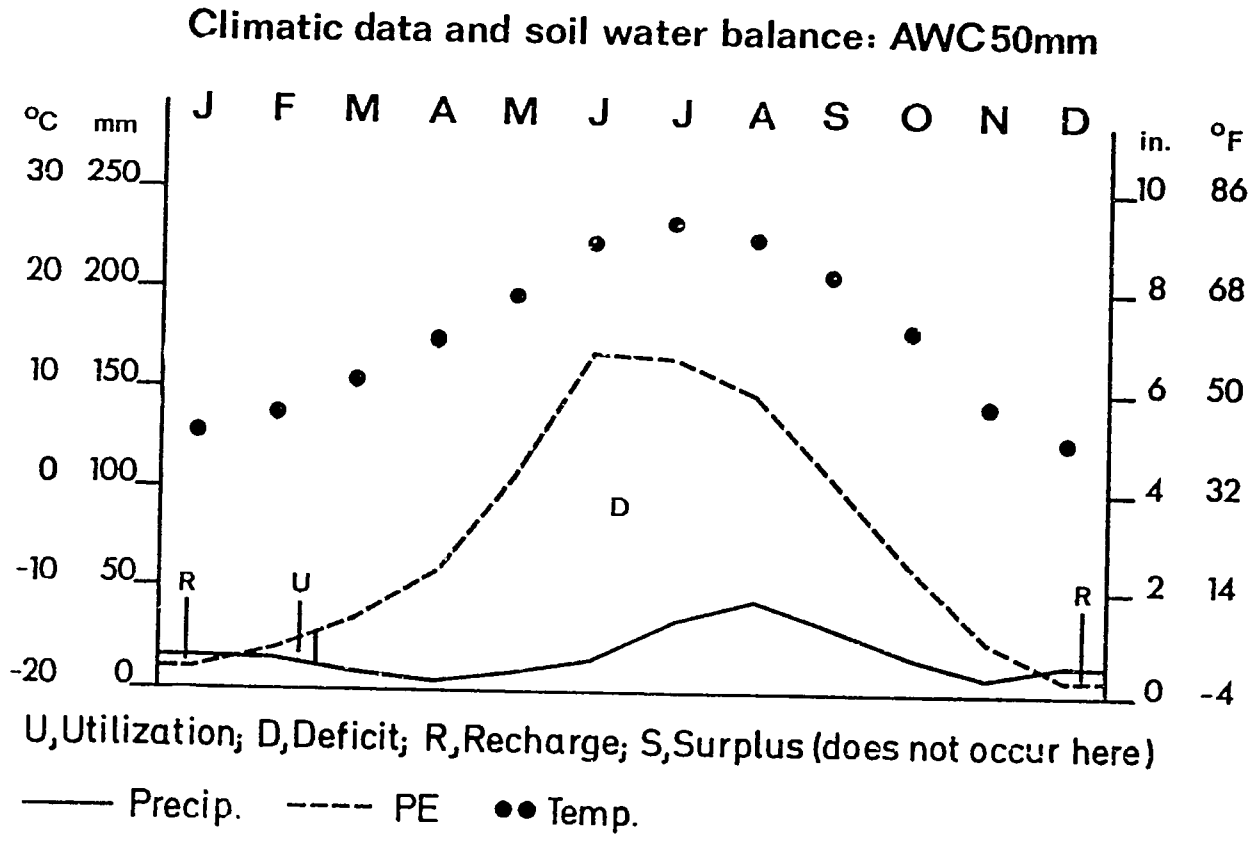


FIGURE 3: Climatic data and soil water balance for a soil that has an aridic (torric) soil moisture regime. (After Soil Survey Staff 1975)

D = period of water deficit, where evapotranspiration is greater than precipitation.

The fourth value, S = surplus, is not relevant because climatic conditions are too dry. The available water capacity (AWC) is given as only 50 mm, i.e. precipitation is too low to fill even the generally much larger pore volume of the soil, which is capable of absorbing water and holding it over longer time periods against the force of gravity.

Some Aridisols were obviously not formed under their present aridic climatic conditions. These show distinct characteristics which could normally develop only under moister climates, e.g. during Pleistocene pluvials. Old soils (Paleosols) are defined in Soil Taxonomy as Paleargids with an argillic B-horizon, and as Paleorthids with a petrocalcic subsurface horizon.

Aridisols in aridic climates are influenced by the negative climatic water balance, i.e. the potential evapotranspiration is greater than the average amount of precipitation. This causes an upward-directed soil moisture movement with a translocation of solutes from deeper to shallower soil layers. These solutes are precipitated once the solubility product of the soil solution is surpassed. The depth of the precipitation zone is dependent on the solubility of the individual salts. Chlorides with the highest solubility undergo the furthest transport, followed by the less soluble sulfate salts and the still less soluble carbonate salts.

If soil solutions move upward because of capillary forces, the solutes are precipitated in the sequence of their solubility (Fig. 4). If mineralized groundwater moves from the saturated to the unsaturated soil zone, stratified layers of carbonates, sulfates, and chlorides are formed, providing conditions are in equilibrium (Fig. 4 according to Kovda, 1973).

A typical soil property of Aridisols is the accumulation of soluble salts and carbonates. Under humid climatic conditions, providing vertical and lateral open drainage systems exist, these alkaline and alkaline-earth weathering products are leached from the soil rooting sphere and from the soil profile and landscape area. In Soil Taxonomy, salt and carbonate accumulation horizons, as formative elements of Aridisols, are distinguished at the great group level (e.g. Natrargids, Salorthids, Gypsiorthids, Calciorthids) from other taxonomical soil units.

Silica enrichment is another phenomenon associated with Aridisols. Silica accumulation in the subhorizons causes hardening and the formation of duripans, which do not slake with water and prevent root penetration. The dry or at least seasonally dry moisture regime prevents, similar to salt accumulations, leaching of the dissolved silica. The occurrence of duripans, however, is largely limited to volcanic areas. Soils with duripans are differentiated at the great group level, e.g. Durargids, Nadurargids, Durorthids.

Accumulations of salts, carbonates, and silica in Aridisols form conditions in the subsurface horizons which often seriously interfere with agricultural land use and with irrigation practices. But the availability of irrigation water may be the only remedy in improving some of the described

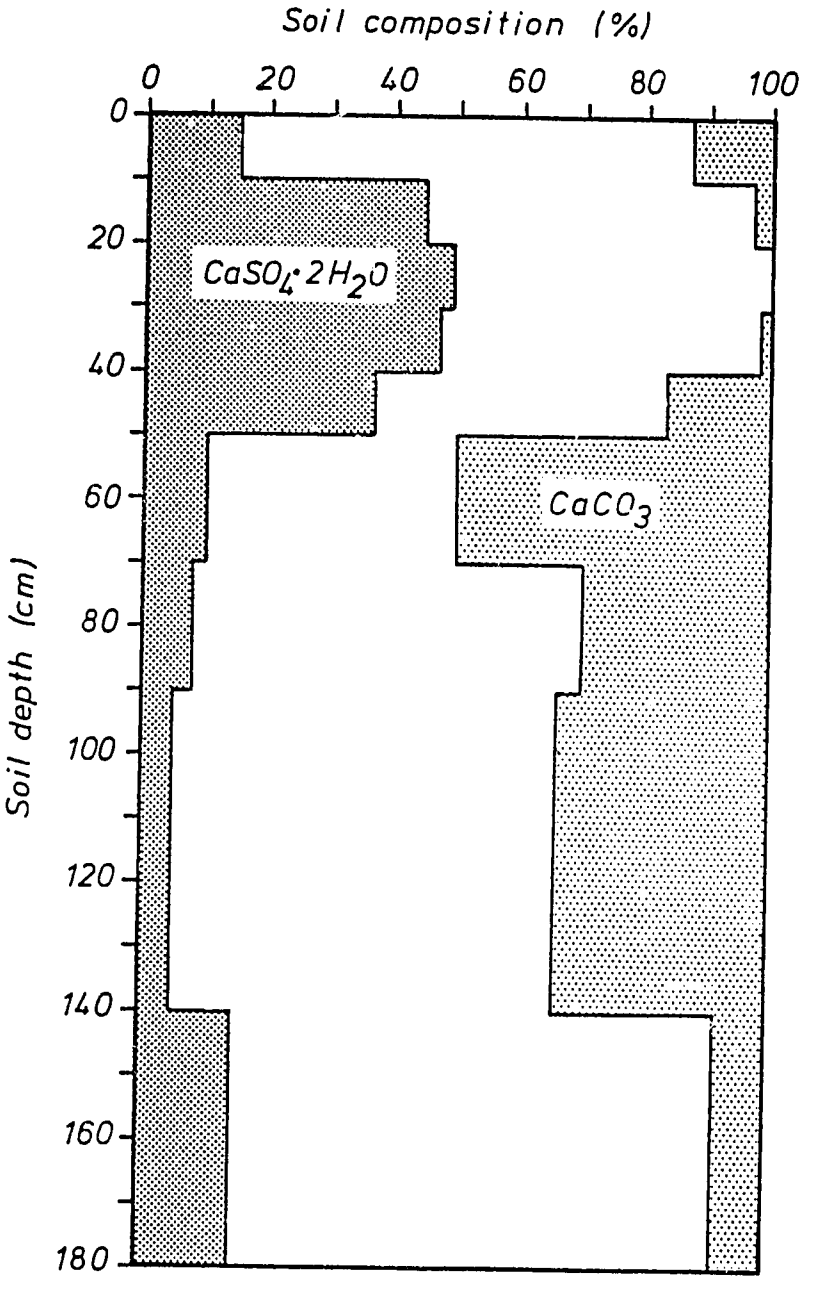


Fig. 4 : Soil with carbonate-gypsum horizons

soil impairments. With the application of water, the aridic SMR would be changed into an udic SMR, eliminating the cause for salt accumulations.

Organisms

Under aridic environments, organisms, flora, and fauna are reduced to a few species which are capable of enduring heat and drought. In the case of higher plants, air temperatures of 50° C and more cause cell death by protein coagulation or desiccation, because high transpiration water losses cannot be replenished at the same rate through water uptake from the soil.

The natural vegetation of aridic areas is adjusted to the inhospitable conditions. Succulents, xerophytic, and tuberiferous plants have special anatomical structures which prevent excessive water losses.

Microorganisms are particularly endurable to unfavorable conditions. Bacteria, actinomycetes, and algae are always present in a dormant state, but revive quickly if conditions improve. Their importance for agriculture is disputed. According to Dregne (1976), algae growth and microbial crusts may reduce water infiltration, though opposite effects may also be encountered.

Nitrogen fixation by free-living microorganisms may be a particular asset to arid-region soils, although the lack of water during most times and the lack of organic carbon for energy may restrict nitrogen fixation.

As a consequence of the limited vegetative growth of higher plants, Aridisols have low organic matter contents. This is indicated by the usually light-colored surface horizon (ochric epipedon). Organic matter contents may increase under irrigation, indicated by a dark-colored epipedon (e.g. Anthropic Camborthid). Higher organic matter contents are also encountered in intergrades of Aridisols, for example in soils with an aquic SMR (e.g. Aquic Haplargid) or under cooler climates (e.g. Borollic Haplargid) or moister climates, where the SMR grades into xeric or ustic subgroups (e.g. Xerollic Natrargid, Ustollic Natrargid).

Topography

The topography is another important environmental factor with significance for soil and landscape development. Fig. 5 is a schematic diagram showing a cross-section of a river valley and the relationship between the fluvial geomorphological surfaces and the typological soil developments. The topographical features are made up of the floodplain with recent fluvial deposits, two terraces at higher levels, and finally the bedrock outcrops on both riverbanks.

All soils are affected by water tables, which fluctuate in the river plain with the changing water levels of the stream. On the terraces, the water tables are a result of less permeable subsoil clay layers. However, lateral inflowing water also flows out laterally from higher places towards the inner part of the valley to join the surface drainage system of the river.

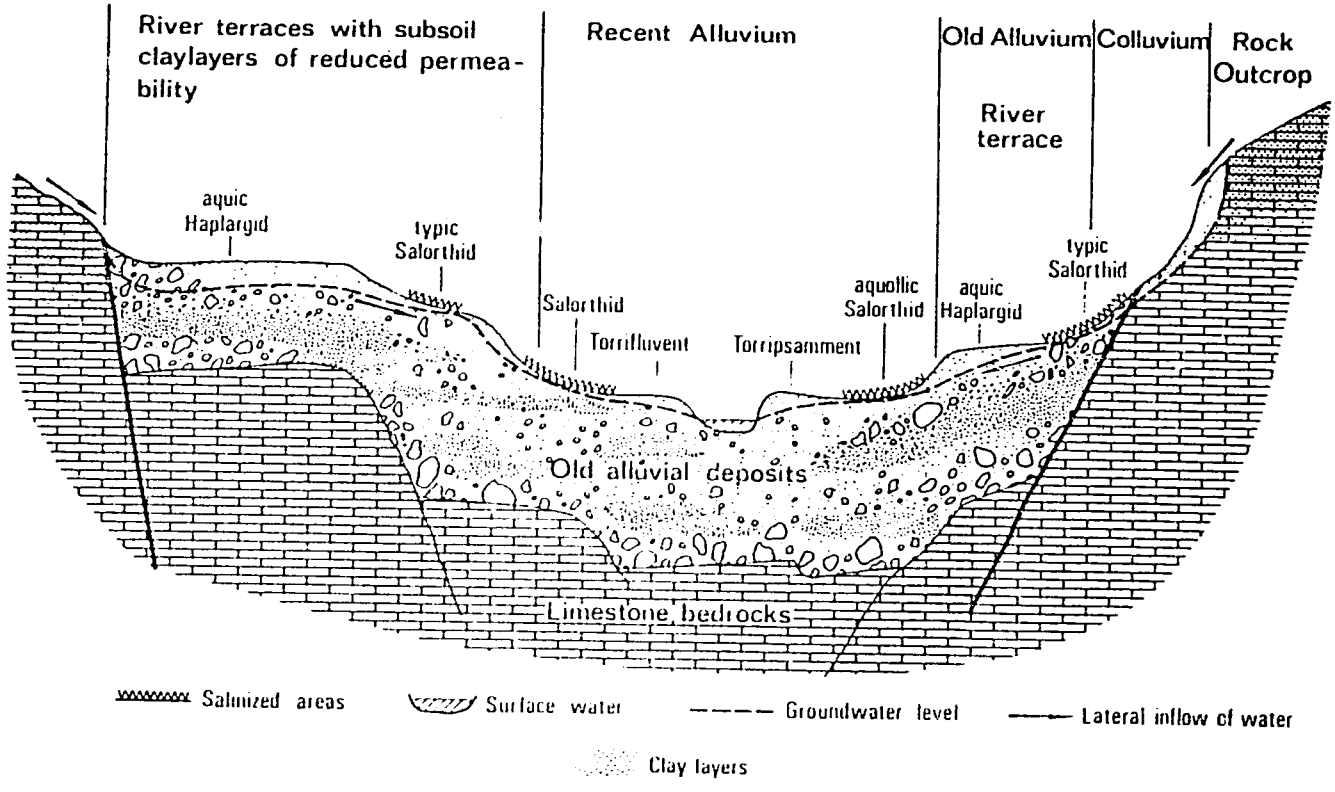


Fig. 5 : Cross section of a river valley showing soil - geomorphic relationships and position of water tables (schematically)

Topographically-dependent salinization develops where water tables come close to the surface, or where surface drainage is impeded due to backslopes with temporary stagnant water tables during high floods. Aquollic Salorthids may develop in these places. In addition, Torripsamments may be found in the adjacent sandy river levees. On the left-hand river bank, Torrifluvents occur on loamy substrates and may be accompanied by Typic Salorthids on the valley rim and foot slope, as well as on the terrace. Haplargids may be found on the older river terrace which represents an older valley floor. Paleargids may also be found, providing these soil formations were developed during Pre-Holocene times. They may also have aquic properties, as shown in the schematical cross-section (Fig. 5).

With respect to land use, the described topographical features and their different soil units have profound effects on suitability. The water tables interfere with arable farming, particularly through the associated salinization processes. The argillic horizons of the soils on the terraces might cause impeded internal drainage, so that perched water tables might be formed periodically.

Hypothetically, the model could be changed with respect to drainage conditions. If the river bed were located at a much deeper level, the water tables would not be as near to the soil surface. Consequently, salinization would be reduced. But seepage with carbonate-containing waters would then be a major influence on soil formation, and Calciorthids would develop on the younger surfaces, and Petrocalcic Paleargids on the older surfaces.

Parent material

The parent material is a most significant soil-forming factor under aridic environments, since weathering processes are less pronounced than under humid conditions. Therefore, the textural and mineralogical composition of the parent material has a significant influence on the properties of arid-region soils. Under extreme arid conditions, physical weathering predominates, but does not lead to clay formation. If the parent material consists of consolidated rocks, mainly coarse weathering products are produced.

Due to hydrolysis, some clay formation takes place under aridic environments. Weathering, particularly by dew, occurs on account of the high amplitudes of day and night temperatures. This causes the formation on a minor scale of colloidal compounds, the so-called "plasma" (Brewer and Sleeman, cited according to Haberland, 1975) including silicate clay minerals. Dissolved iron, manganese, and siliceous compounds and colloidal compounds are precipitated on rock surfaces forming crusts, desert varnish and cutans appearing as darkly colored polishes (Fig. 6). To some extent, microorganisms, capable of metabolizing the oxidizable iron, manganese and titanium compounds, participate in the formation of these surfaces.

The major parts of clays in Aridisols, however, originate from geologically pre-weathered materials, such as sedimentary rocks, shales, clays and siltstones. Since alkaline pH's are prevalent, because the soluble products of weathering are not leached out from the soil sphere, conditions

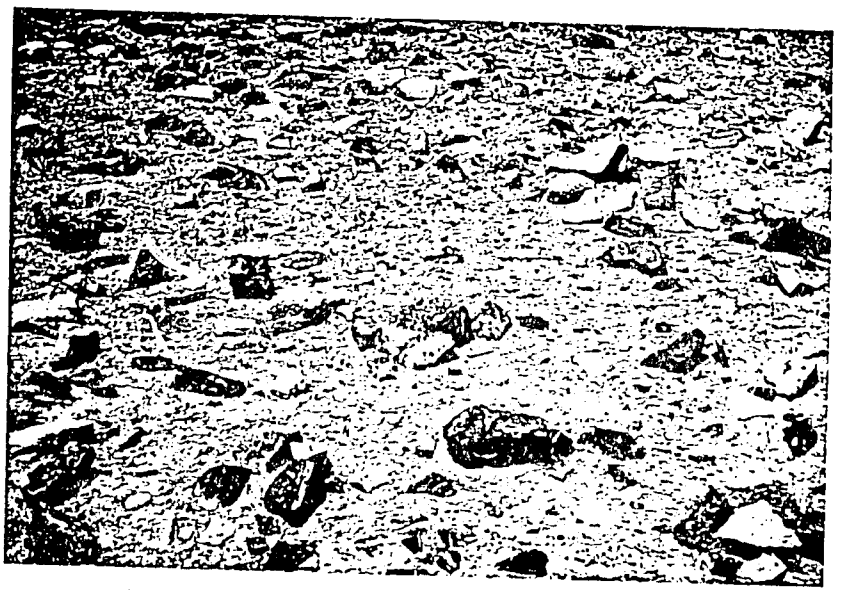


Fig. 6: Desert varnish on limestone rock

are favorable for montmorillonite clay mineral formation. If illite is present in the parent material, it could remain unweathered for considerable periods, because of the low chemical weathering intensity of aridic climates. In comparison with montmorillonite, kaolinite, gibbsite and others, illite is generally the most easily weathered clay mineral (Dregne, 1976).

Time

Time has been included by Jenny (1941) as a soil-forming factor. It refers to older surfaces with Paleosoils which have preserved some morphological features caused by a soil-forming environment that no longer exists (Gile et al., 1981). Since pedogenic weathering is slight and leaching very restricted, the time function is mainly recognizable from carbonate and soluble salt dislocations. Consolidation of these layers, i.e. the formation of petrocalcic and petrogypsic horizons, as well as the illuviation of clay to form an argillic B-horizon, is mainly attributed to geological times older than Holocene. This also implies stability of landforms over geologic time, because otherwise erosion and sedimentation processes would have changed these pedomorphic relief features.

DIAGNOSTIC HORIZONS AFFECTING PLANT GROWTH

The discussion focuses on the properties of Aridisols with respect to their horizontal differentiation and their influence on plant growth. Aridisols are separated at the suborder level into Argids with an argillic horizon and into Orthids without an argillic horizon. Further diagnostic criteria of the subsurface horizons are reflected at the great group or subgroup level. These are cambic, natric, salic, calcic, and petrocalcic, gypsic and petrogypsic, and the occurrences of a duripan. Subsequently, a few examples of profiles will be discussed, where diagnostic horizons have particular relevance to plant growth.

Argillic horizons

Soils with argillic horizons are heteromorphic with respect to soil texture. A clay-enriched subsoil horizon is usually found a few decimeters below the soil surface. According to the Soil Taxonomy definition, an argillic horizon must have at least a 1.2 fold higher clay content than the A-horizon above, and must have a thickness of 1/10 or more of the A-horizon.

It is assumed that clay migration, producing an argillic horizon, can only take place under higher rainfall conditions than provided by aridic climates. Therefore, most argillic horizons were probably formed during moister climatic periods. Furthermore, clay migration only takes place if the soil is carbonate-free, since carbonates keep the clay in a flocculated state preventing migration within the profile over larger distances. Dispersion of clay, however, and translocation can also be caused by higher sodium contents.

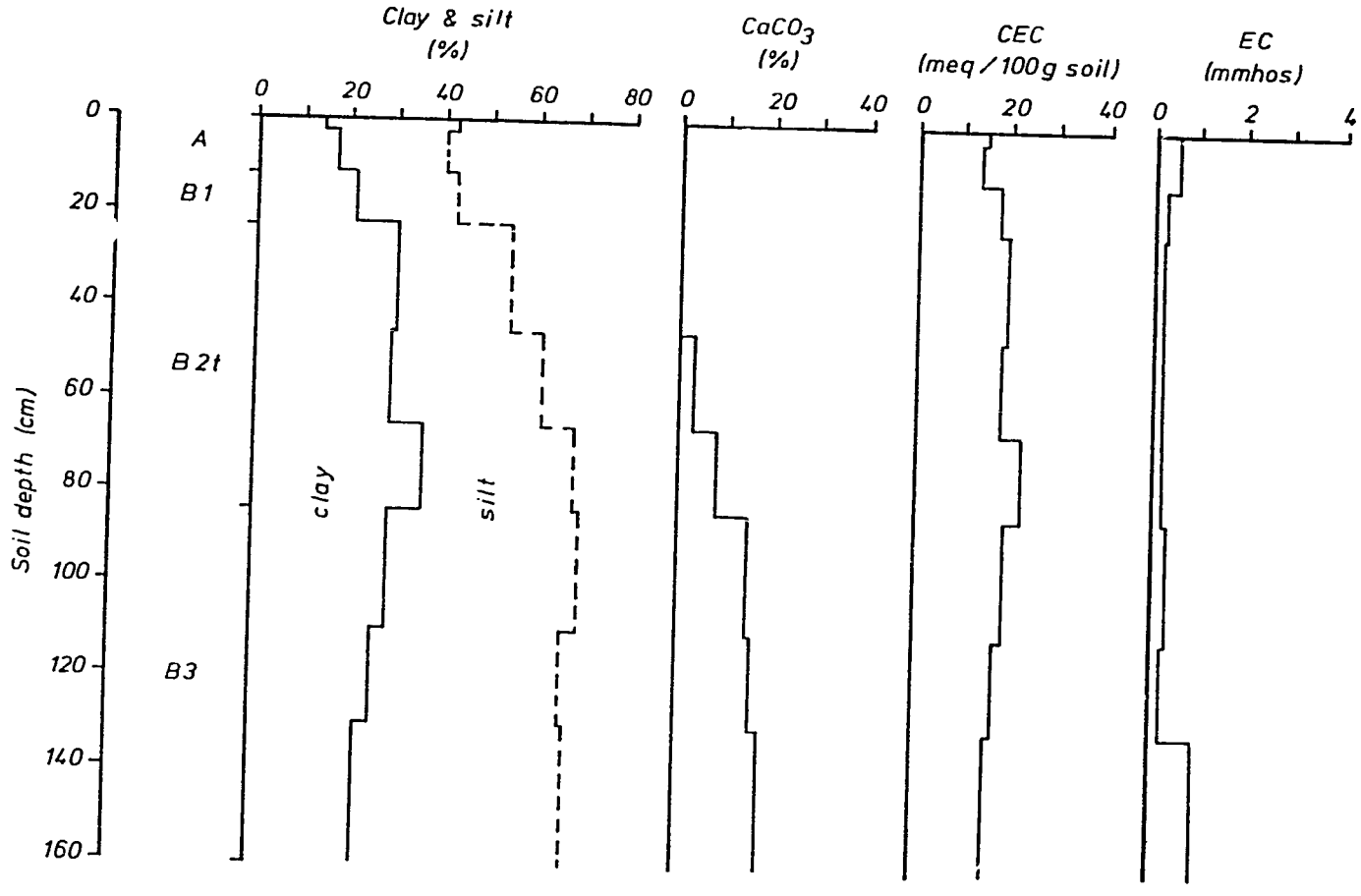


Fig. 7: Typic Haplargid (Arizona, USA)

A Typic Haplargid is shown in Fig. 7 (Pedon 57 in Soil Taxonomy). The increase in clay content of the Bt ranges between 9-15% and reaches a maximum of 36%. The clay content generally remains below 35%, which is the limiting value given in Soil Taxonomy for differentiation between Haplargids, Paleargids and Vertisols. The colors of the horizons are brown to light-brown (7.5 YR) and not reddish (5 YR) as often encountered in Paleargids. Carbonates are leached to a depth of 45 cm. Soluble salts are absent.

Fig. 8 shows a Calcic Haplargid (Lenthe, 1978) with a shallow argillic horizon of only 23 cm depth but with medium and high carbonate contents of 20% in the epipedon and of 50% in the Bt.

The Typic Paleargid in Fig. 9 (Pedon 59 in Soil Taxonmy) has a total clay content of 60% in the Bt, which is approximately 40% more than in the A-horizon. The soil is carbonate-free, with the exception of 3% in the middle part of the profile.

Finally, a Petrocalcic Paleargid is illustrated in Fig. 10 (Pedon 60 in Soil Taxonomy). It is an example of a soil with cemented subsurface horizons.

The soils described and their respective diagnostic horizons have direct implications concerning choice of plants which may be grown and their potential growth performance. Typic Haplargids with a gradual change of textural classes betwen surface soil and subsoil have a sufficiently large rooting volume potential, since layers impeding root penetration do not exist. This must be seen in contrast with Calcic Haplargid, with a highly calcareous horizon in the middle part of the profile. The restriction of rooting depth is even more pronounced in the Paleargids shown in Figs. 9 and 10, especially when the subsoil is petrocalcic (Fig. 10). Although some of these calcite enrichments may still be permeable to water, as demonstrated by infiltration experiments in Jordan (Burghhardt, 1970), the root penetration of most plants is impeded, probably due to the adverse physical and chemical composition.

The argillic horizons of the profiles shown may represent an advantage in terms of the enlargement of the water storage capacity, provided the textural boundaries are not too abrupt. An example for such sudden textural change is shown for the Typic Paleargid in Fig. 9, where a difference of 40% clay content was registered. The change in pore size at the boundary between the horizons is indicated by the differences in water-holding capacity. At the 28 cm depth, between the transitional A 3 and the B 21 horizon, the 1/3 bar values change in their water-holding capacity from 18 to 40% and the 15 bar values from 7 to 21.6%. There is an interruption in the capillary flow of water within the profile and interference with infiltration properties. If carbonates are additionally embedded in the Bt-horizon (Fig. 10), the coarse pores, which are very important for internal drainage, may further be reduced in number and size.

Duripans

According to Soil Survey Staff (1975), the formation of Duripans occurs under aridic climates when soils are usually dry or seasonally dry. Strongly

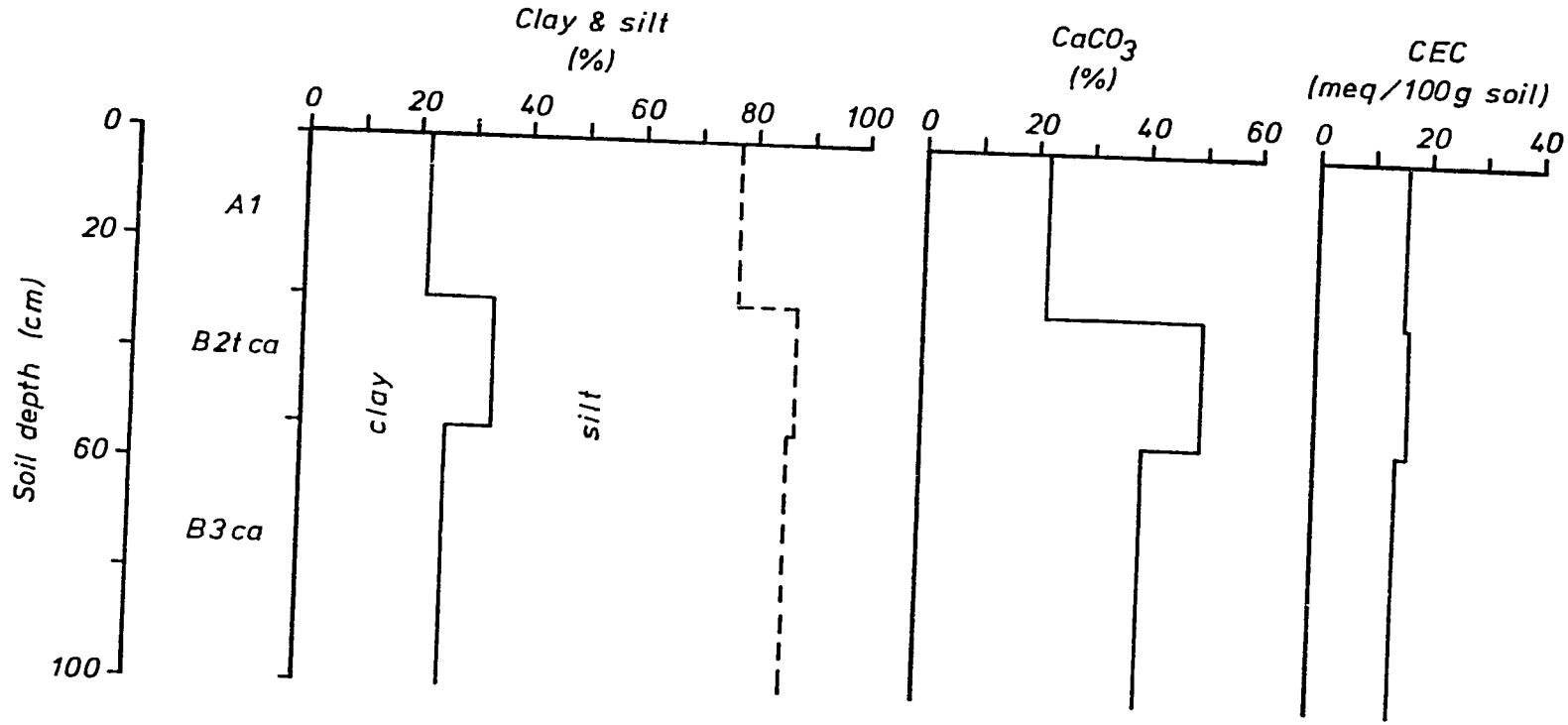


Fig. 8 : Calcic Haplargid (Raydah, Yemen A.R.)

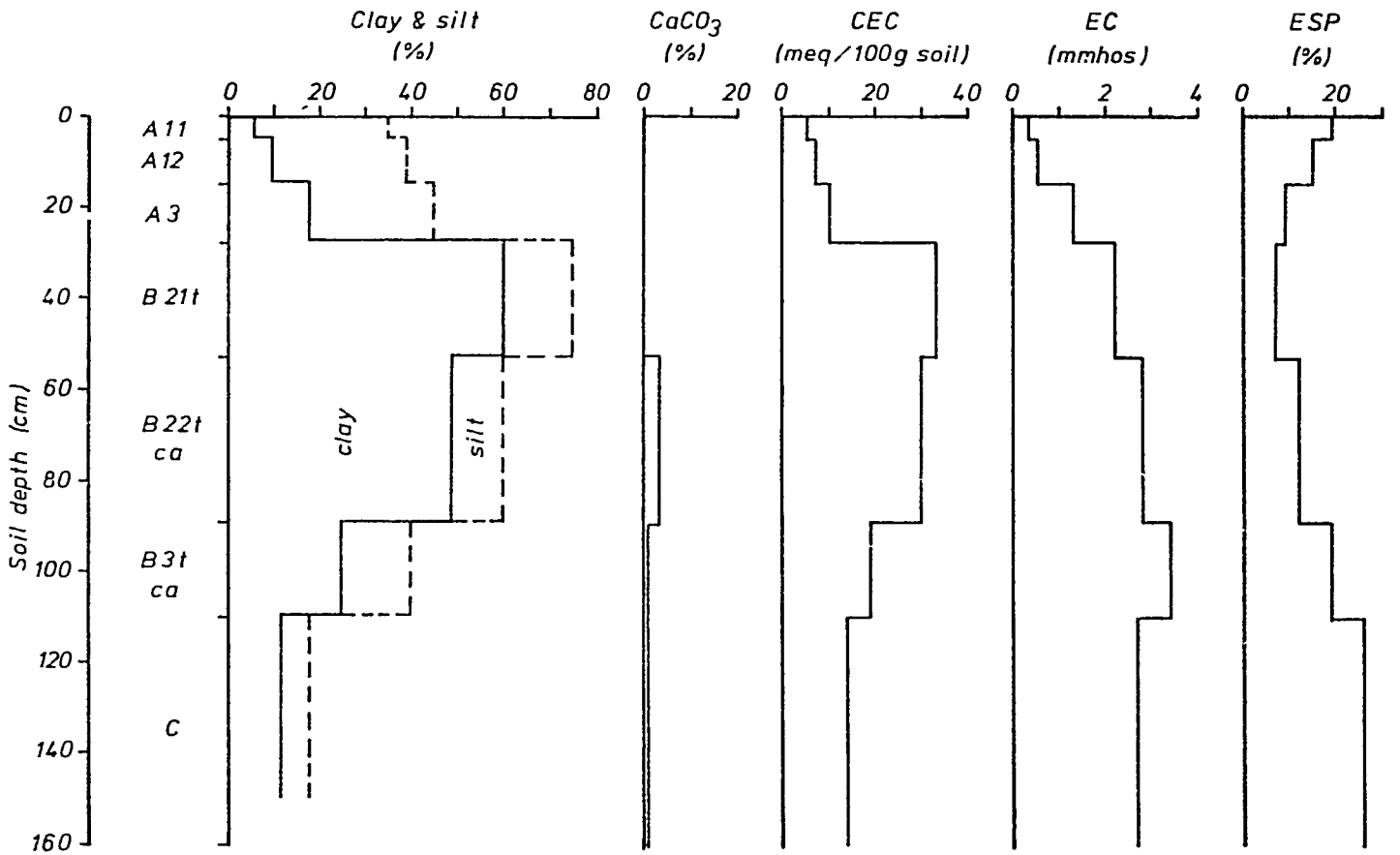


Fig. 9 : Typic Paleargid (Arizona, USA)

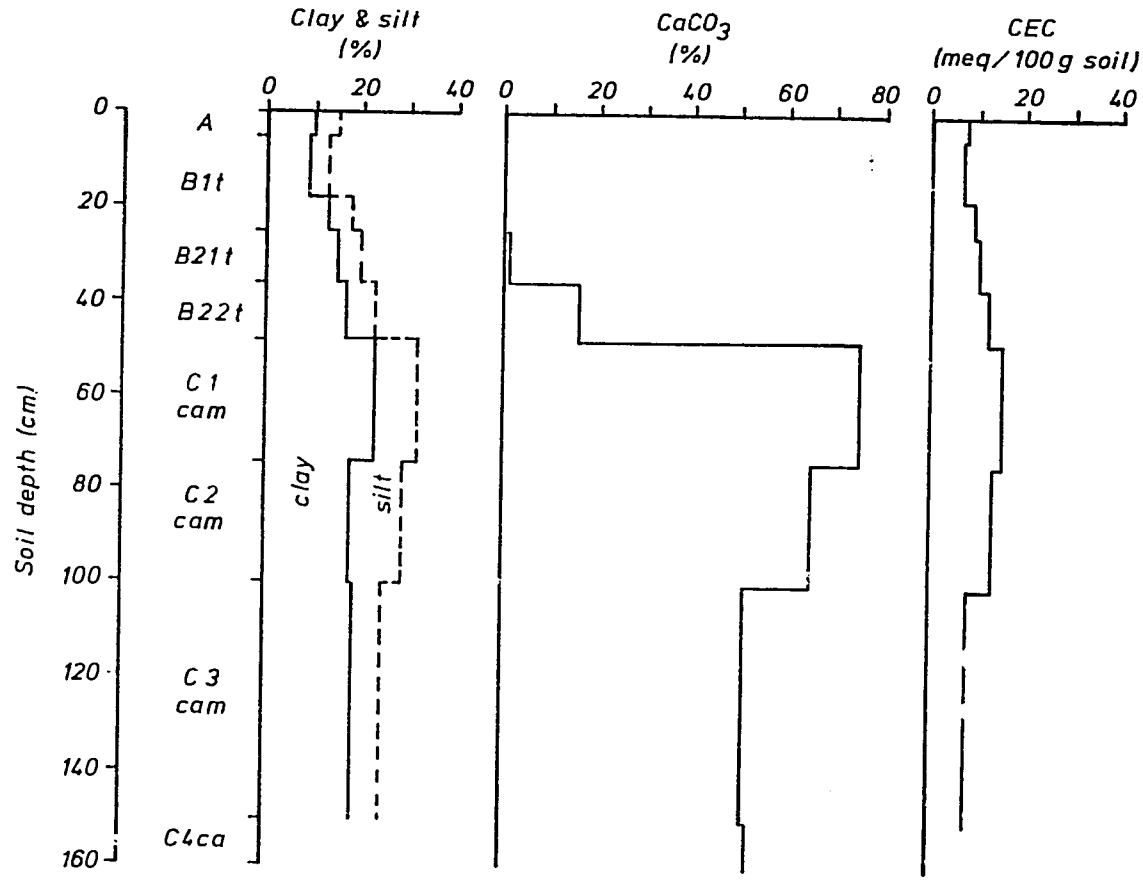


Fig. 10: Petrocalcic Paleargid (New Mexico, USA)

cemented duripans are usually platy and the plates are 1 to 15 cm thick. Duric horizons develop particularly in soils derived from pyroclastic materials.

In Fig. 11 a typic Durargid (Pedon 56 in Soil Taxonomy) is graphically represented on the basis of the analytical data given in Soil Taxonomy. The Bt is very distinct, with a 33% increase in clay content compared with the transitional horizon above, and an absolute clay content of 50%. The duric horizon is located below the Bt, mainly between 58 and 97 cm depth. The cemented duric horizons have a massive to weak coarse platy structure which is extremely hard when dry and extremely firm when moist.

Roots, as indicators of structural and chemical inadequacies, do penetrate slightly into the duric horizons, but only appear beneath the duric horizon in fractures before ceasing completely. In comparison with the argillic horizons, the water content in duric horizons is reduced and also the cation exchange capacity is lower. But otherwise, except perhaps for slightly increased sodium contents and pH's, no significant analytical values are found that clearly characterize duric properties. Further duric characteristics would be increased $CaCO_3$ content and higher conductivity values of the saturation extracts. It would appear that the morphological criteria observable on the profile are the best indicators of duric properties.

Natric horizons

The influence of a natric horizon is shown in Fig. 12, a typic Natrargid (Pedon 58 in Soil Taxonomy). A natric horizon is defined in Soil Taxonomy as an argillic horizon with additional structural properties such as columns or higher contents of exchangeable sodium (> 15 ESP). From the graph in Fig. 12 the increase in clay content and in particular in the ESP value with increased depth is most apparent.

Fig. 13 represents a Natrargid from Yugoslavia. It is similar to the soil in Fig. 12, but without carbonate contents in the upper part of the profile (Zivkovic, 1978).

The structure of the B-horizon is hard when dry and sticky when wet. This causes a reduction in coarse pore space as shown in Fig. 13. Below 50 cm depth there is a very limited volume of drainage pores which could lead to stagnant water in the profile and to perched water tables. This would seriously interfere with leaching processes and result in further sodium accumulation.

Salic properties

According to Soil Taxonomy, salic properties in higher classification categories are diagnosed when the soil contains 2% or more secondary enrichment of salts in at least 15 cm thick horizons or when the product of thickness in cm and salt percentage by weight is 60 or more.

As an example, a Calcic Salorthid is illustrated in Fig. 14. The soil is located in the Southern Highland of Jordan. The parent material

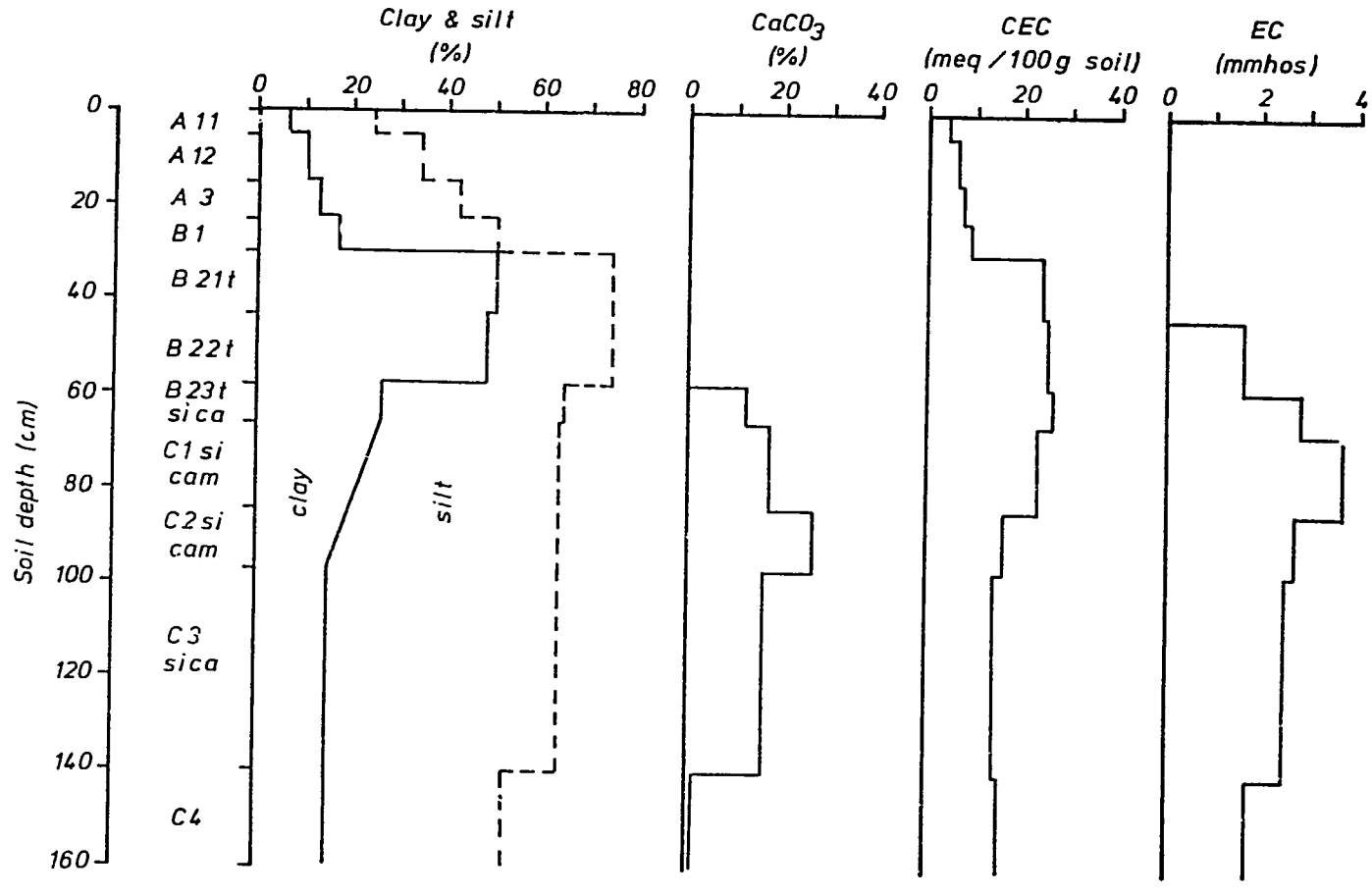


Fig. 11: Typic Durargid (Arizona, USA)

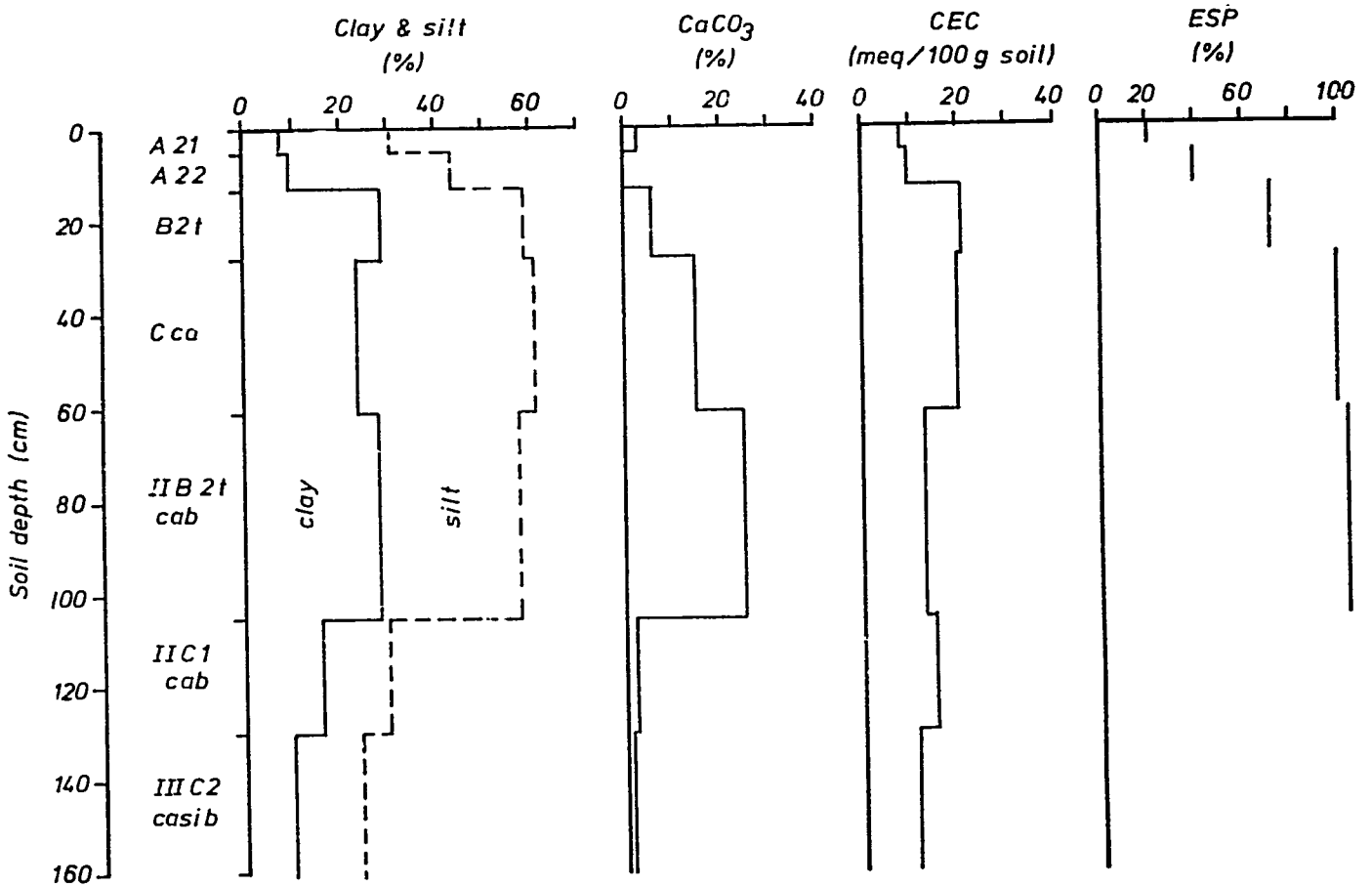


Fig. 12 : Typic Natrargid (Arizona, USA)

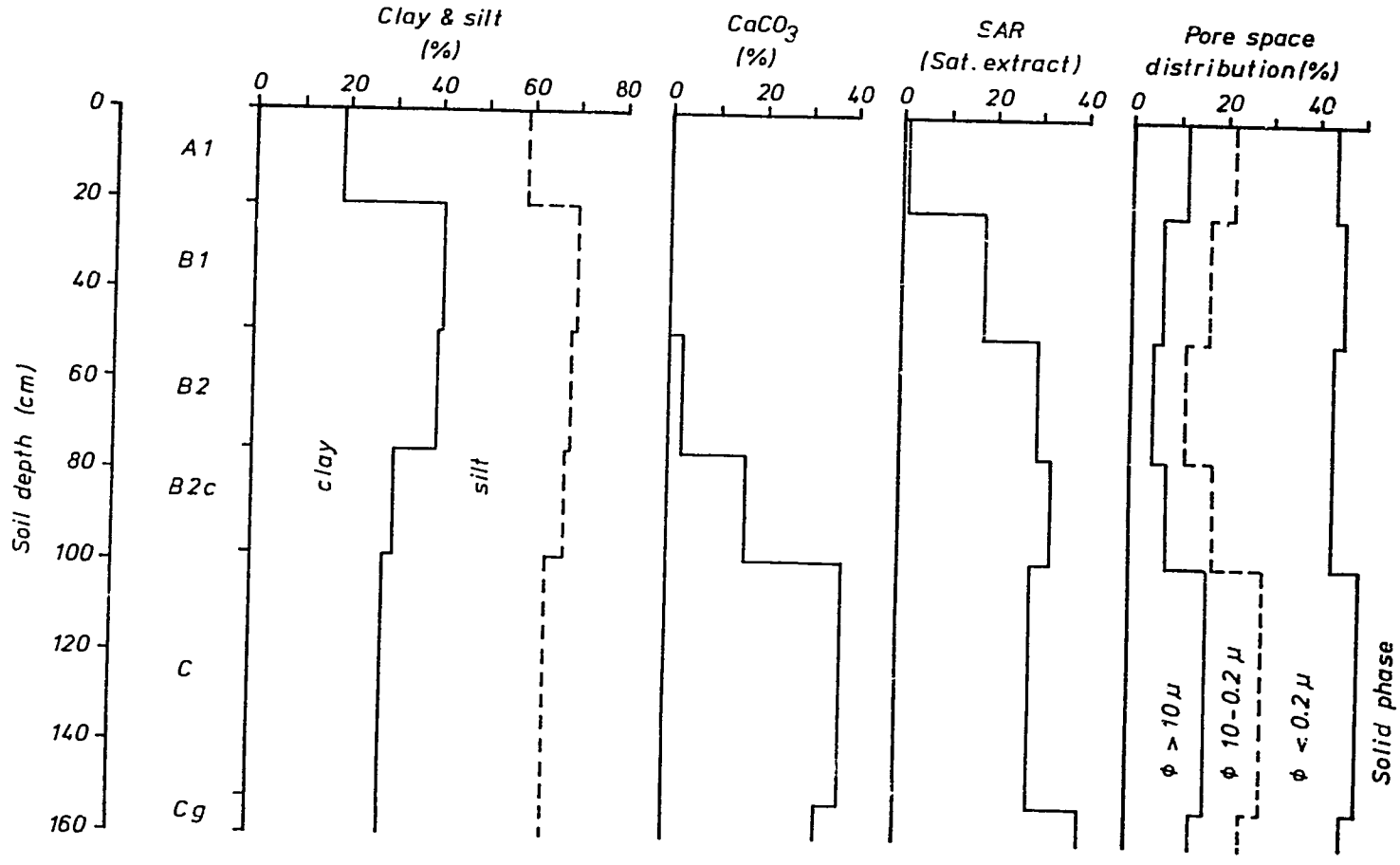


Fig. 13: Natrargid (Vojvodina, Yugoslavia)

originated from Pleistocene fan deposits and is composed of pre-weathered limestone mixed with some basalt material. The loamy soil has extremely high contents of soluble salts throughout the profile, but with maximum concentrations between 5 and 70 cm depth. The carbonate contents are evenly distributed throughout the profile, amounting to roughly 30%.

Some associated soils in the same area have lower salt contents but otherwise similar characteristics as illustrated in Fig. 15. This soil can be classified as a Salic Calciorthid, since it does not qualify for a salic diagnostic property at the great group level. With respect to plant growth, however, the salic properties of the Salic Calciorthid (Fig. 15) make it unsuitable for normal plant growth. The measured 11 mmhos/cm electrical conductivity value of the 5-15 cm soil depth is only suitable for salt-tolerant plants. The extreme salt concentrations of the Calcic Salorthid (Fig. 14) prevent any plant growth.

Gypsic horizons

Finally, a Calcic Gypsiorthid with gypsic diagnostic criteria is illustrated in Fig. 16 (ACSAD, 1980). A gypsic horizon is defined according to Soil Taxonomy as an enrichment of secondary sulfates that is 15 cm or more in thickness and has at least 5% more gypsum than the C-horizon. The product of thickness in cm and percentage of gypsum must be 150 or more. The soil is located in Syria on the terrace of the Euphrates River. The graph shows a decrease of carbonates, and an increase of sulfates towards depth.

The values for exchangeable sodium percentage (ESP) are high for 10 to 40 cm depth, where gypsum is low. Below this the ESP is normal. Salinity is uniform at 10 mmhos/cm throughout the profile. The salts consist of Cl^- and SO_4^{--} in about equal proportions. The solubility of gypsum is obviously higher than chlorides are present (60 meq/l instead of 30 meq/l).

Gypsic soil layers are not penetrated by roots, when the concentrations exceed 30% (ACSAD, 1980). The soils become very hard when dry, and dense and nonporous when irrigated. They are susceptible to erosion due to the high gypsum and silt contents.

LAND CAPABILITY AND MANAGEMENT

Land capability can only be assessed in relation to the type of land use and appropriate management practices. As an example of the broadest groups of land use, we can differentiate land capabilities for irrigation, for rainfed agriculture, for rangeland, and for forestry. The respective management requirements are altogether different for these broad groups, but they also vary greatly within these groups, depending on the ecological and economical conditions of the specific site. A few examples are given.

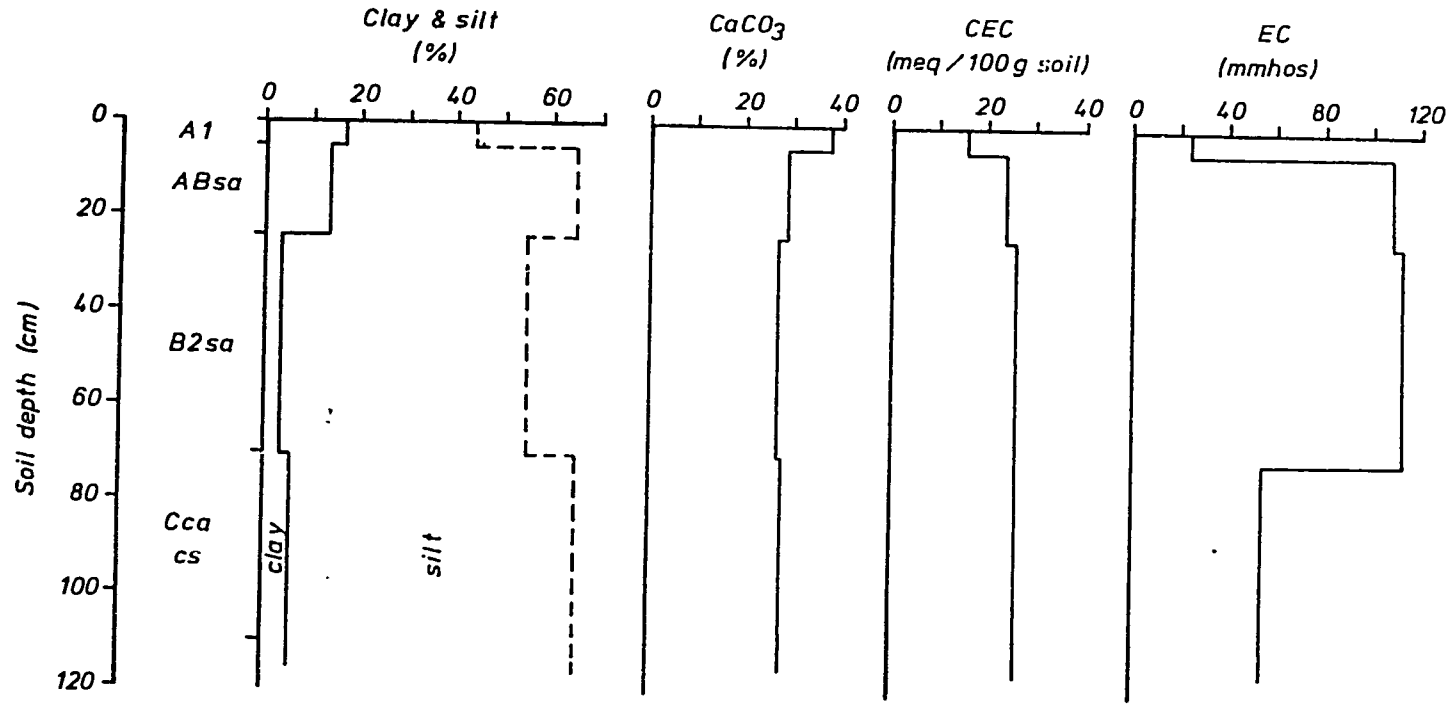


Fig. 14: Calcic Salorthid (Wadi Arja, Jordan)

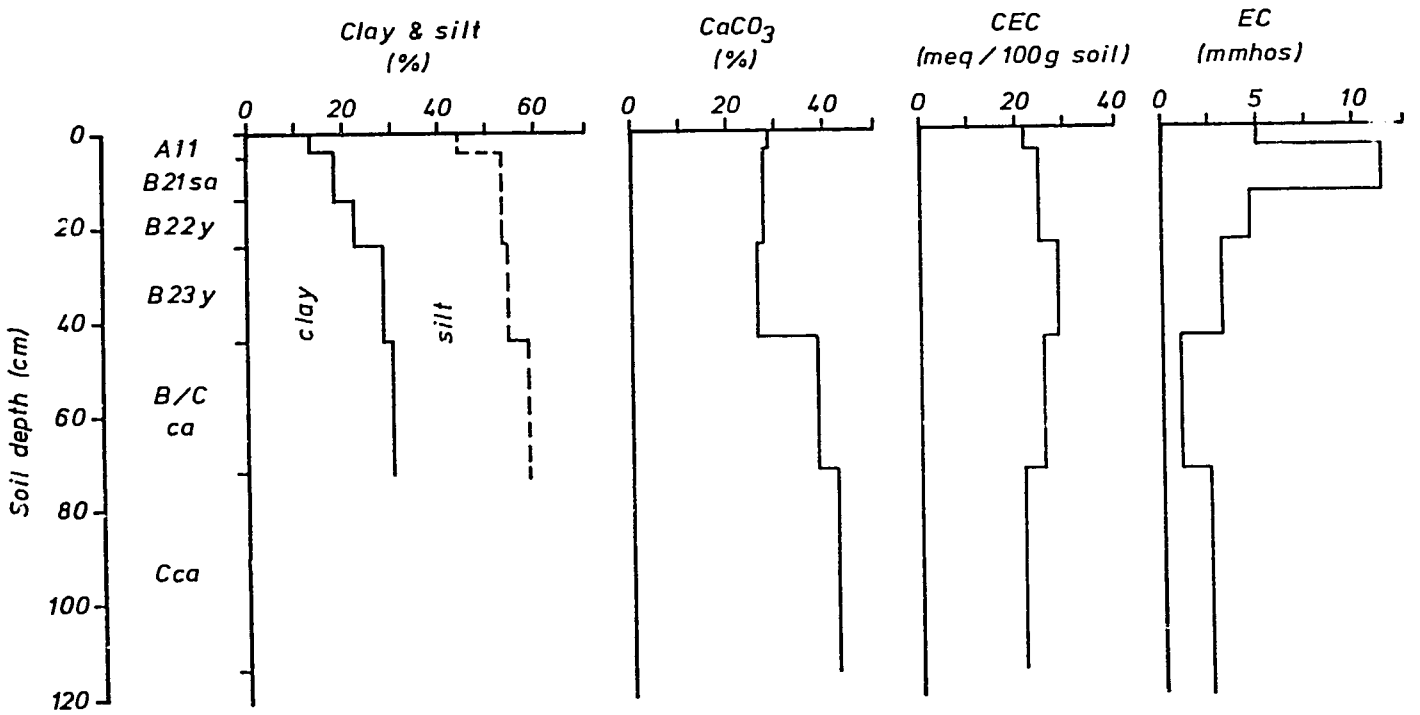


Fig. 15: Salic Calciorthid (Wadi Arja, Jordan)

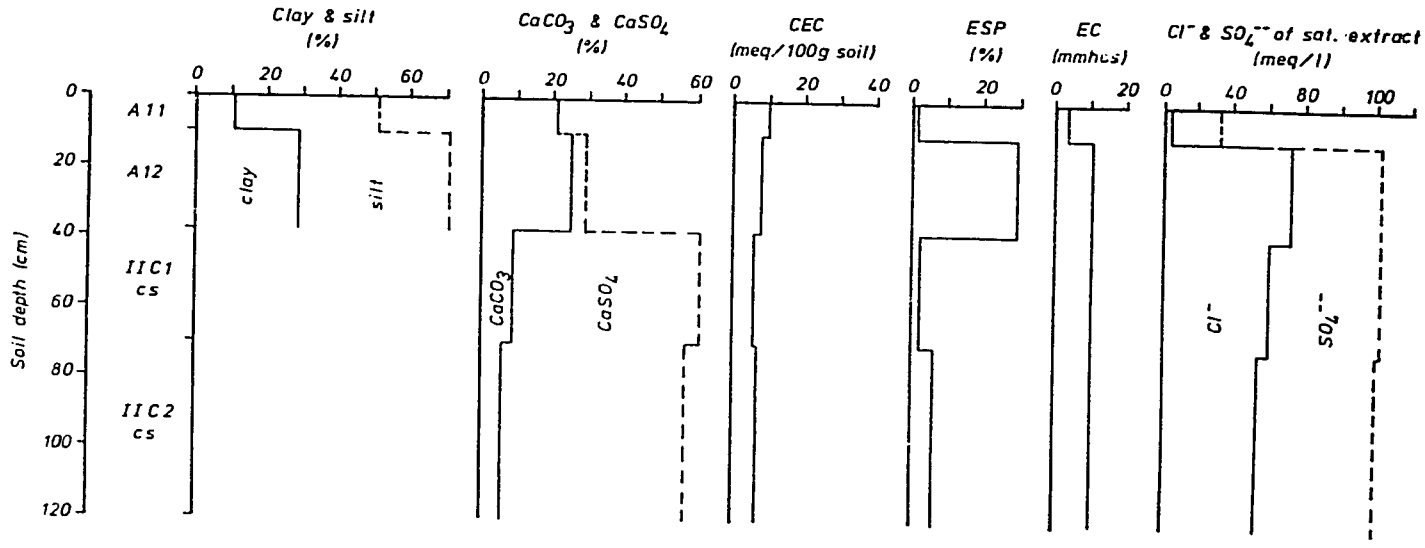


Fig. 16: Calcic Gypsiorthid (Deir El Zor, Syria)

Irrigation

For the evaluation of irrigated land use, the three major resources involved--soil, water, and plant--must be included in the study.

Some soil quality criteria are a prerequisite for irrigated land use:

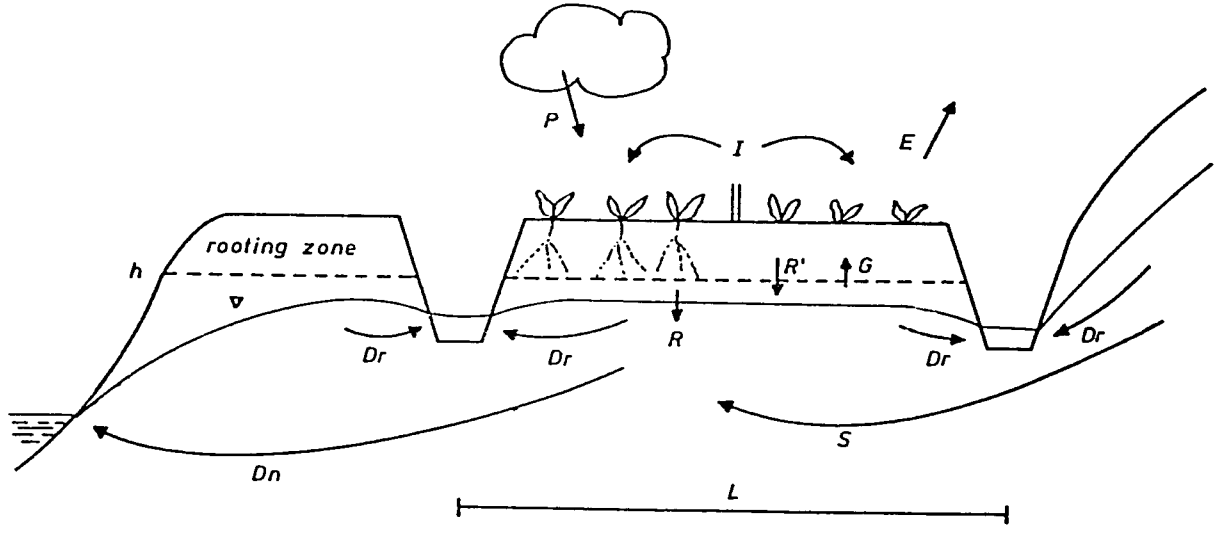
- Water permeability, so that the water balance provides a net-percolation of salt-loaded drainage water through the profile;
- a connecting hydrological system which secures the outflow of drainage water from the irrigated area; and
- sufficient porous volume of the soil for water storage.

Some of these prerequisites for succcessful irrigation of Aridisols are illustrated in Fig. 17. The net-percolation, given as the difference between the percolation and the capillary rise, is the decisive factor in the control of the salt balance of the soil, i.e. so that salts do not accumulate in the rooted zone. This net percolation corresponds to the leaching requirement (LR) formulated by the U.S. Salinity Laboratory (1954). It defines the fraction of irrigation water in excess of evapotranspiration needs, required to pass through the soil into the outflow system. In many cases, artificial drainage has to be introduced. The maximum permissible rise of the water table is controlled by the depth and distance of drainage ditches. Soils like Petrocalcic Paleargids (Fig. 10) or Durargids (Fig. 11) or especially Natrargids (Figs. 5, 12, and 13) do not provide sufficient natural drainage. Breaking of crusts and the installation of artificial drainage is unavoidable.

An experimental leaching procedure and its effectiveness is illustrated in Fig. 18 (Lüken and Nitsch, 1970). The Calcic Salorthid soil requires approximately 1200 mm of water before the salts are leached to a depth of about 80 cm. The salts remaining in the profile produce an electrical conductivity between 1.5 and 5 mmhos/cm. Given proper management, this does not present problems for irrigated land use.

Lower water applications were used under field conditions (pre-irrigation with 685 mm). The polders were planted with alfalfa and irrigated with a total of 1783 mm in 16-day intervals. The soil structure deteriorated gradually during cultivation. Analysis revealed a substantial increase in pH and ESP (Table 1) and a reduction in coarse pores which are important for the internal drainage of the soil (Table 2, polder C 07). This is due to insufficient leaching, i.e. the remaining salts (about 8 mmhos at 45 cm depth, see Fig. 18) moved upwards by capillary suction, and the sodium ions are largely adsorbed by the exchange complex. At high pH's the $CaCO_3$ has only a low solubility (about 1 meq/l). Therefore, the soil was converted from a saline-nonalkaline soil, to a nonsaline-alkaline soil. The water quality was not an influencing factor, because it had a low sodium adsorption ratio (SAR) and a low residual bicarbonate ratio.

The importance of the coarse porous volume for internal drainage is illustrated in Fig. 19. The pedologically formed Bt-horizon increases the amount of fine pores with high suction pressures for water and decreases the coarse porous volume. Heterogenic porous distribution does interfere with the effectiveness of salt leaching.



I effective irrigation
P effective precipitation
E evapotranspiration
G capillary rise
R percolation
R net - percolation (R=R'-G)
Dr drainage
Dn natural drainage
L distance between drains
S seepage water
h permissible height of the groundwater table

Fig. 17: Water household of an irrigated field (after van der Molen, 1976)

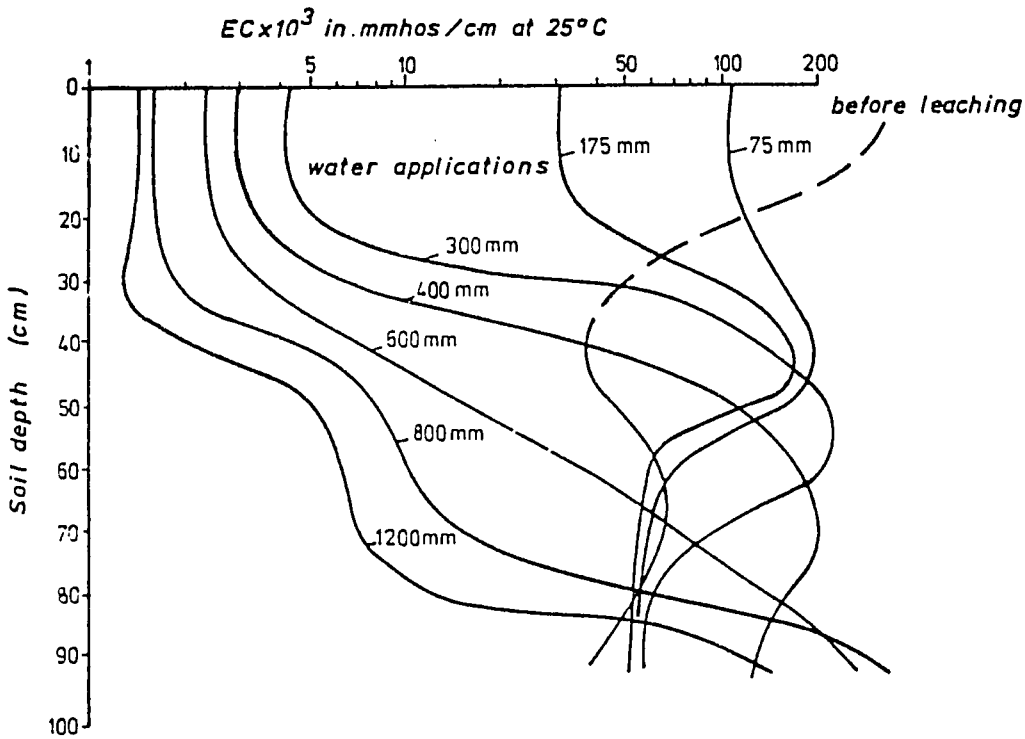


Fig. 18: Salt leaching of a Calcic Salorthid in Southern Jordan (see also Fig. 14)

Table 1. Chemical soil characterization - EC (saturation extract), pH and ESP - of Wadi Arja, Plot C 07 May, Aug., Dec. 1973.

Depth of sampling	Autumn 1972 after 685 mm			May 1973			August 1973			December 1973			
Depth (cm)	EC	pH	ESP	EC	pH	ESP	EC	pH	ESP	Depth (cm)	EC	pH	ESP
0-15	0.93	8.4	18.4	1.47	8.2	17.2	1.00	8.05	10.6	0- 26	3.02	8.56	20.1
15-30				1.33	8.5	22.7	1.20	8.36	15.0	26- 38	2.35	8.99	30.4
30-45				1.47	8.6	24.7	2.65	8.40	23.3	40- 52	2.86	8.96	35.8
45-60				2.06	8.5	21.6	6.02	8.20	20.3	56- 75	6.79	8.55	29.6
										80-103	20.94	8.25	34.6

(Grüneberg et al., 1969; Grüneberg, 1975)

Table 2. Physical soil characterization and pore size distribution of Wadi Arja, Plots L 2 and C 07.

Plot Exp. I L2 (nonsaline - nonalkaline)					Polder C 07 (nonsaline - alkaline)					Difference Exp. I L2 - C 07			
Depth of sampling (cm)	Total pore volume (%)	> 10 μ vol %	10-2 μ vol %	< 2μ vol %	Depth of sampling (cm)	Total pore volume (%)	>10μ vol %	10-2μ vol %	< 2μ vol %	Total pore volume (%)	>10μ vol %	10-2μ vol %	>2 μ vol %
0-15	53.7	16.9	22.9	13.9	11-16	41.0	3.8	9.0	28.2	-12.7	-13.1	-13.9	+14.3
15-30	49.3	16.0	11.3	22.0									
30-45	46.8	15.9	9.4	21.5	26-38	43.0	5.2	9.8	28.0	- 3.8	-10.7	+ 0.4	+ 6.5
45-60	49.2	28.0	8.0	13.1	50-55	42.8	8.6	8.9	25.3	- 6.6	-19.4	+ 0.6	+12.2
60-75	52.9	29.6	10.8	12.5									

(Grüneberg et al., 1969; Grüneberg, 1975)

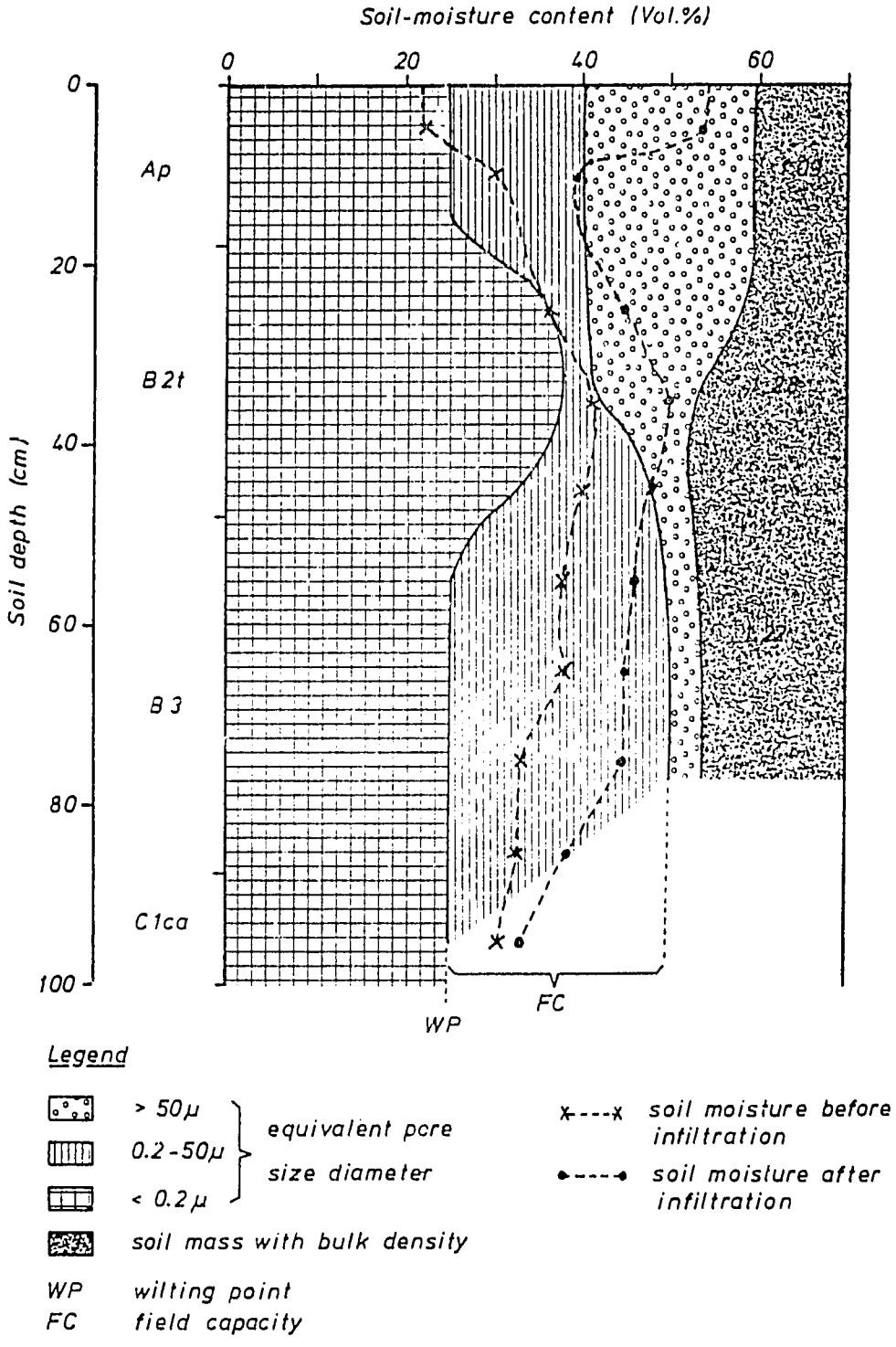


Fig.19: Poresize distribution of a Rhodoxeralf

Rainfed agriculture

Rainfed agriculture under arid conditions must be seen under a completely different perspective. As investigations have shown (Lüken, 1975), land selection under arid and semi-arid climates for rainfed agriculture is more difficult than for irrigated agriculture. Some soil qualities are very critical when water is scarce, e.g. the water storage capacity, the rate of water infiltration, and the rooting volume. Some of these limitations can be compensated for by irrigation.

Under dryland, loess-like soil materials are particularly suited because they have a high water-holding capacity. If a fallow system is used, sufficient moisture can be stored to supplement the limited rainfall during the cropping year. Fallow systems are used in semi-arid climates with 200-400 mm rainfall. The method consists of cropping in alternative years with a fallow period in between. The moisture stored in the fallow year is only a small portion of the rainfall received, but it generally secures sufficient yields.

The tillage practices under rainfed agriculture must conserve water. Plowing must be shallow to prevent drying of deeper soil layers. The soil must have a rough surface, so that rainfall runoff is minimized. Crop residues must be maintained at the soil surface so that a soil-protecting mulch is created which conserves moisture and reduces erosion by wind and water.

If rainfall is below 200 mm, tillage farming is generally prohibited because of very low yields. The soil surface will be bare and unprotected over long periods. Destructive effects of direct sun, wind, and water will easily lead to desertification (UNCOD, 1977). Increased attention has to be paid to soil protection. Slight slopes promote excessive runoff. Contour farming, where tillage and planting operations are carried out across the slope of the land, with parallel ridges and furrows, reduces water runoff. Terracing is effective against soil erosion. Soil removal in hilly land, however, must be carried out in accordance with profile characteristics. Infertile soil horizons and raw parent materials should not be exposed to the surface.

Water-collecting systems can greatly enhance and secure yields under low rainfall conditions. These systems are still in operation in the Middle East (Lenthe, 1978; Lüken, 1975) and elsewhere. More modern systems in other areas are known as "water-harvesting" and "runoff management" systems.

Rangeland

Rangeland management under arid conditions is comprised mainly of rough grazing by permanent pasturalism or by nomadism. Rangeland management requires, in particular, ecologically adapted forms with an equilibrium between plant productivity, soil conservation, livestock density and use of water resources. According to UNCOD (1977), land degradation is most severe in rangeland areas. It is affecting yearly 3.2 million ha, as compared with 2.5 million ha for rainfed farmland and 0.125 million ha for irrigated farmland.

The management requirements consist almost solely of the manipulation of the grazing animals to attain an intensity of forage use that maintains normal forage growth and soil productivity (Wasser et al., 1957). Forage plants tolerate only a certain degree of foliage removal by the animals, and it is necessary to reduce grazing during times of low productivity. Plant coverage breaks the impact of rain and prevents puddling of soil. It minimizes raindrop splash and dislodging of soil particles and protects the soil from erosion.

Land use as rangeland by nomadism is an extensive production system of low cost, but of high desertification potential (UNCOD, 1977). Grazing lands in nomadic herding regions usually need very large areas to sustain the animals, though this varies with the precipitation available.

Cattle require ranges of higher quality and more water to drin than goats and sheep. Cattle can only be raised in areas with higher rainfall than that available in aridic zones.

Table 3. Area required to feed one livestock unit.

Annual rainfall (mm)	No. of ha per livestock unit
50 - 100	50 or more
200 - 400	10 - 15
400 - 600	6 - 12

(UNCOD, 1977. Background Document, Technology, and Desertification)

Grazing land, according to UNCOD (1977), does not deteriorate as long as plant productivity and animal pressure are in equilibrium. It is suggested that management practices include revegetation for fodder production in accordance with adaptability to soil and climate, to palatability and to general improvement measures, so that seasonal deficiencies and land degradation can be avoided.

Forestry

Afforestation would help to stabilize the land and provide wood for fuel in rural areas. A careful appraisal of environmental conditions is necessary. Shelter belts and windbreaks combat erosion and provide shaded areas for animals.

Reforestation can generally not be carried out without supplemental irrigation, required at least during the youth stage of the trees. It is also possible to plant trees in low spots where runoff water collects. The choice of species requires the greatest attention. For example,

Prosopis chilensis, a Mesquite species, was successfully introduced in the Sudan in 1928 (Kassas, cited by UNCOD, 1977). It is drought-resistant and provides fuel wood as well as fodder, and as a shelter belt, protects the soil against erosion.

SUMMARY AND CONCLUSIONS

The "Properties and Management of Aridisols" was discussed on the basis of definitions of Aridisols according to Soil Taxonomy (Soil Survey Staff, 1975). A thermo-pluvial diagram was developed which shows the interdependency of Aridisols with soil moisture and soil temperature regimes. Aridisols, in the strict sense, account for only one-third of arid soils.

The pedological properties of Aridisols are largely determined by the negative water balance, where potential evapotranspiration is higher than precipitation. The upward-directed soil moisture flow causes the accumulation of salts in the rooting zone. This has a high impact of agricultural land use and on necessary management procedures.

Some soil properties of Aridisols have been inherited from previous climatic periods. Paleargids and Paleorthids are soils with argillic or petrocalcic horizons. These characteristics influence the water-holding capacity and the root penetrability of the soil.

The management of Aridisols has to take adaptability of plants and of cultural methods into consideration. Economical as well as ecological viewpoints must be combined. Ameliorative measures, such as the leaching of salts, are expensive but often unavoidable. If natural conditions become more adverse, measures of soil protection will gain in significance. The spreading of desertification is a warning symptom of worldwide dimensions.

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MANAGEMENT OF ARIDISOLS IN THE SUDAN

M. O. H. Elkarouri

ABSTRACT

Aridisols are of common occurrence in northern Sudan where their requirements are fulfilled by the desert and arid climatic conditions. They are encountered as far south as Northern Gezira, but with increasing aridity toward the north, they dominate the old Nile terraces.

The present use of Aridisols in Sudan is minimal because it is marginal land with some constraints that limit its development. Nearly all the suitable land of the floodplain, particularly in the northern region, has already been developed. Any further expansion must be on the Aridisols of the Nile terrace. The main problems associated with the development of Aridisols are:

- wind erosion and sand creep,
- widespread salinity and sodicity, and
- high water requirements of crops and high irrigation cost.

To minimize wind erosion and restrict sand creep, shelter belts must be planted. Shelter belts of trees require more work in the years of establishment, but less maintenance effort compared to other inanimate barriers. Research on shelter belts on Aridisols is presently being carried out in the northern province.

Development of Aridisols could make use of the excellent Nile water, but groundwater could offer an alternative source in the areas which overlie Nubian sandstone. However, crop water requirements in Aridisols are expected to be higher than the Vertisols of the Gezira due to the difference in irrigation efficiency in the two areas: 55-60% on Aridisols, and 80-85% on Vertisols.

Salinity and sodicity are the major constraints to the development of Aridisols. Salinity increases northward with aridity. The dominant salts are NaCl and Na_2SO_4.

Various agronomic and soil management practices pertinent to the improvement of saline and sodic soils were investigated at Soba experimental farm south of Khartoum, where the soils are predominantly Aridisols, but not typically representative of the Aridisols of the northern region.

Aridisols are problematic soils which require certain reclamation measures if high productivity is to be attained. However, they are reclaimable, and the climatic conditions of Northern Sudan are favorable for the production of high-value crops such as pulses and spices. The traditionally intensive arable cropping practices in the region may justify the higher inputs required for their development.

THE MANAGEMENT OF THE SOILS OF THE NILE VALLEY

H. Hamdi, R. Tinsley, and A. Taher

In the Cretaceous Period, almost 50 million years ago, Egypt and a large part of Africa was submerged beneath the sea. At the end of this period, however, the sea retreated gradually northwards, and the Cretaceous deposits raised to form dry land, and thus became subjected to denudation by the action of rain and river. The limit of sea retreat cannot be ascertained, but it was at least as far as Cairo-Beni Sweif. Also during the different periods from Eocene (30 million years ago) till the recent period there have been many cycles of advance and retreat of the land and sea. Therefore, deposits of gravels and sands have been laid down in the Pleistocene and more recent periods.

The clay that covers the flat floor of the Nile Valley and forms the arable land has been deposited by the floodwaters in the course of the recen geological period. Beneath the uppermost part of the deposits, there is a considerable thickness of mixed sand and silt deposited from the river during Paleolithic and Neolithic times (almost 10,000 - 8,000 B.C.). However, due to the rising sea level, the Nile was aggrading its bed and raising its floodplain relatively rapidly.

The development of soils in the Nile valley took place under the activity of a number of agencies. The activities of ancient times could be shown in the different cycles of levels of both land and sea, as well as in the depositions of a thick layer of different deposits that belong to the different geological periods.

Recent activity, however, could be represented by the River Nile deposition, thus forming a uniform layer that measures an average thickness of about 9 m, and took almost 10,000 years (Ball, 1952). The thickness of the Nile deposition in Upper Egypt amounted to 6.7 m, while in the Delta 11.2m. The variation may result either from the irregular surfaces of the underlying old deposits, or to the fact that the Nile from time to time changes its path. The Nile Delta measures about 175 km from north to south and almost 220 km from east to west.

The activity of ancient times formed the macro-relief, while the recent formed the micro-relief.

CLASSIFICATION

From the pedological point of view, the alluvial soils of Egypt belong to the Azonal, the Entisols, and Vertisols. They are young soils with no

generalized pedogenic characteristics. The difference between them is a matter of texture, with its associated properties, as well as of the influence of management practices.

The arable soils (the Holocene alluvial deposits) belong to the great soil groups Typic Torrifluvents, Vertic Torrifluvents, and Typic Torrerts. The last great soil group is incompletely defined in Soil Taxonomy. The Vertisols in Egypt need further classification in subgroups and phases according to salinity, alkalinity, $CaCo^3$ content and gypsum.

MANAGEMENT PRACTICE

The effect of management practice on these soils is very recent and related to the land use and irrigation practice.

From 8000 B.C. up to about 1800 A.D., the soils of the southern part of the Delta were under basin irrigation system (water covers the land for 40 days, then the water is released to the Nile and the land is cultivated). The area was more or less in terraces. On the other hand, in the northern part of the Delta the branches of the Nile and the natural canals flowed freely over the land and the regular deltaic formation was strongly developed. At 1800 A.D., the basin irrigation system was converted to the perennial one in Lower Egypt, while a part of Upper Egypt remains irrigated by the old system which has been changed to the perennial one after the construction of the High Dam in 1964.

With regards to the management of these clayey soils, the Vertisols, which contain high amounts of fine clay, need special consideration in respect to plowing, irrigation, and drainage. The most conspicuous feature is their ability to shrink and swell upon change of moisture content, whereas fissures of considerable width are formed. The morphological characteristics of these soils in Egypt are: friable, calcareous, water retentive, having the ability to expand and contract reversibly due to wetting and drying, root penetration almost in the upper 30 cm, high C.e.C. The profile shows an almost uniform content of clay with a coarsening upward in the sand content. They have high water table but no signs of mottling. The reason could be attributed to the fact that irrigation waters which are regularly applied are oxygenated.

The fine clay is dominated by well-crystallized montmorillonite, and abnormal dioctahedral iron-rich smectite. The clay fraction is fine, giving a large surface area for water adsorption, and thus a high volume of soil water. A representative profile has the following morphology:

Profile	Description
Location:	Shebin El Kom, Menoufyia Governorate
Elevation:	11 m.a.s.l.
Landform:	Floodplain
Topography:	Level
Water table:	150 cm
Vegetation:	Fallow after maize (*Zea mays*)
Classification:	Typic Torrerts

Depth	Description
Ap 0- 30 cm	Dark brown (10 YR 3/3 m); clay; medium subangular; firm; sticky; plastic; fine pores; few soft and hard lime concretions; many fine and medium roots; diffuse smooth boundary.
30- 60 cm	Dark brown (10 YR 3/3 m); clay; medium subangular blocky; very firm; very sticky; few fine pores; no roots; weak effervescence; clear smooth boundary.
60-120 cm	Dark brown (10 YR 3/3 m); clay; strong fine angular blocky; coarse parallelepiped aggregate due to intersecting slickenside; extremely hard; very sticky; very plastic; moderate fine pores; weak effervescence.

The analytical data read as follows:

Table 1. Particle size distribution and some chemical properties of a Vertisol.

Depth (cm)	Ph	Clay (%)	Silt (%)	F.Sand (%)	C.Sand (%)	$CaCO_3$ (%)	TSS. (%)	OM. (%)
0- 30	8.0	55	31	12.0	1.8	2.5	0.05	1.4
30- 60	7.8	53	37	7.5	2.0	1.3	0.14	1.1
60-120	7.7	56	34	7.1	1.9	1.7	0.26	1.0

Table 1.1 Soil Bulk Density Variability with Depth and Distances.[a]

Depth (cm)	Bulk Density					
0- 18	1.40	1.37	1.26	1.44	1.34	1.49
18- 30	1.63	1.51	1.53	1.50	1.60	1.67
30-120	1.59	1.46	1.47	1.43	1.43	1.60

[a]Sampled area is 25 x 150 m. Drainage Project No. 149 Egypt.

Table 1.2. Soil Moisture Characteristics of Soil in El Minya.

Depth	Moisture Content at Specific Atmosphere Tens.					
	0.10	0.33	0.66	1.0	3.0	15.0
	% Volume					
0-30	67.2	55.6	49.2	49.9	40.7	31.7
30-120	67.2	59.7	57.0	57.5	45.0	33.7

Irrigation

In irrigating these soils, very large amounts of water are consumed during the initial irrigation compared to the subsequent irrigations. This behavior is due to the fact that water runs through the wide cracks and the subsequent volumetric changes in the soil will lead to a very low infiltration rate and slow permeability. However, the relatively small subsequent irrigations are applied not to replenish soil moisture, but to prevent the effect of drying on soil consistency.

The properties of Vertisols affect the irrigation system throughout all aspects of water management:

Conveyance losses. The wetting and drying conditions result in an exceptionally unstable conveyance system, in which compaction is impossible to maintain, and excessive seepage losses occur. This is noticeable in elevated irrigation waterways such as within farm canals, where length can reach 500 m. Measurement of conveyance losses amounted to 30-50% of water lifted (Fig. 1).

The occurrence of soil sealing makes it necessary for the farmers to have some means of surface drainage. This need may be the primary reason that farmers subdivide their fields into small basins served by deep, small channels, which, in turn, may hinder mechanization.

Infiltration. Once water reaches the individual fields, infiltration can proceed within 15-30 minutes from an initial very rapid rate to completely sealed soil in which essentially no measureable infiltration occurs. The infiltration will proceed in a two-phase log-log-rate. The initial phase will usually take 10-15' which represents the infiltration through the wide cracks. The second phase continues for the remainder of the irrigation. This is thought to represent the infiltration through soil pores. This phase usually shows a decreased rate of decline for furrow irrigation, but an increase for basin irrigated cover crop. The second phase, however, will drop to zero, indicating a completely sealed soil. Fig. 2 shows infiltration curves under two irrigation systems.

Water movement. Once water has actually entered the soil profile, the redistribution can be exceptionally slow. During winter when ET rates are minimal, gravity flow within the upper 30 cm may extend over 14 days. After this, soil water losses will approximate the ET rate for the area and crop. Also most of the soil water changes are restricted to the upper 30 cm. Below that, the variation in soil water content between irrigations are in the order of 2.5 cm for the 30-60 cm depth, and 1.5 cm for the 60-90 cm depth. These lower depths are almost continuously near saturated soil moisture level, even under the best-drained conditions.

Fig. 3 shows a detailed soil water analysis.

This general wet condition raises the question of possible aeration problems. Estimating of percent soil water shows the possibility of saturation conditions frequently occurring even in the 15-30 cm layer and almost continuous saturation below this (Table 2).

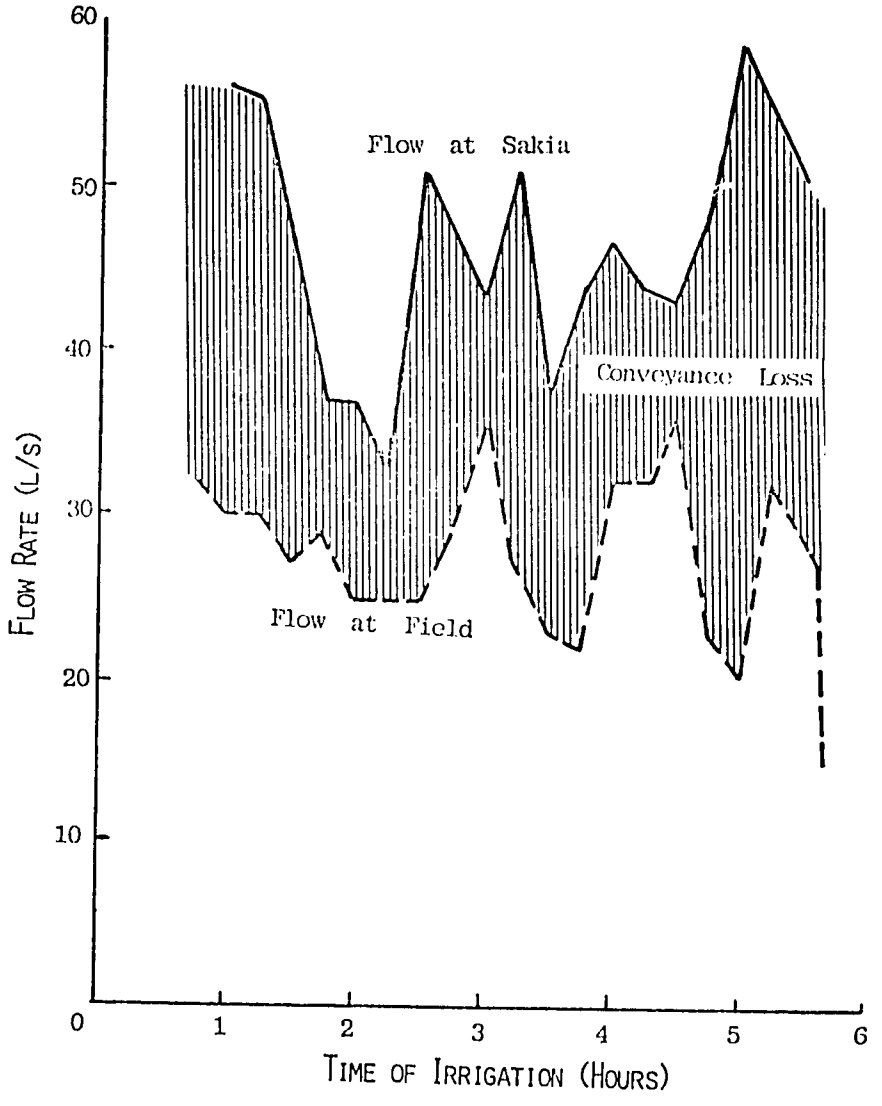

Figure 1. Example of on-farm Marwa conveyance losses during a single irrigation; Abo Raia, Kafr El Sheikh.

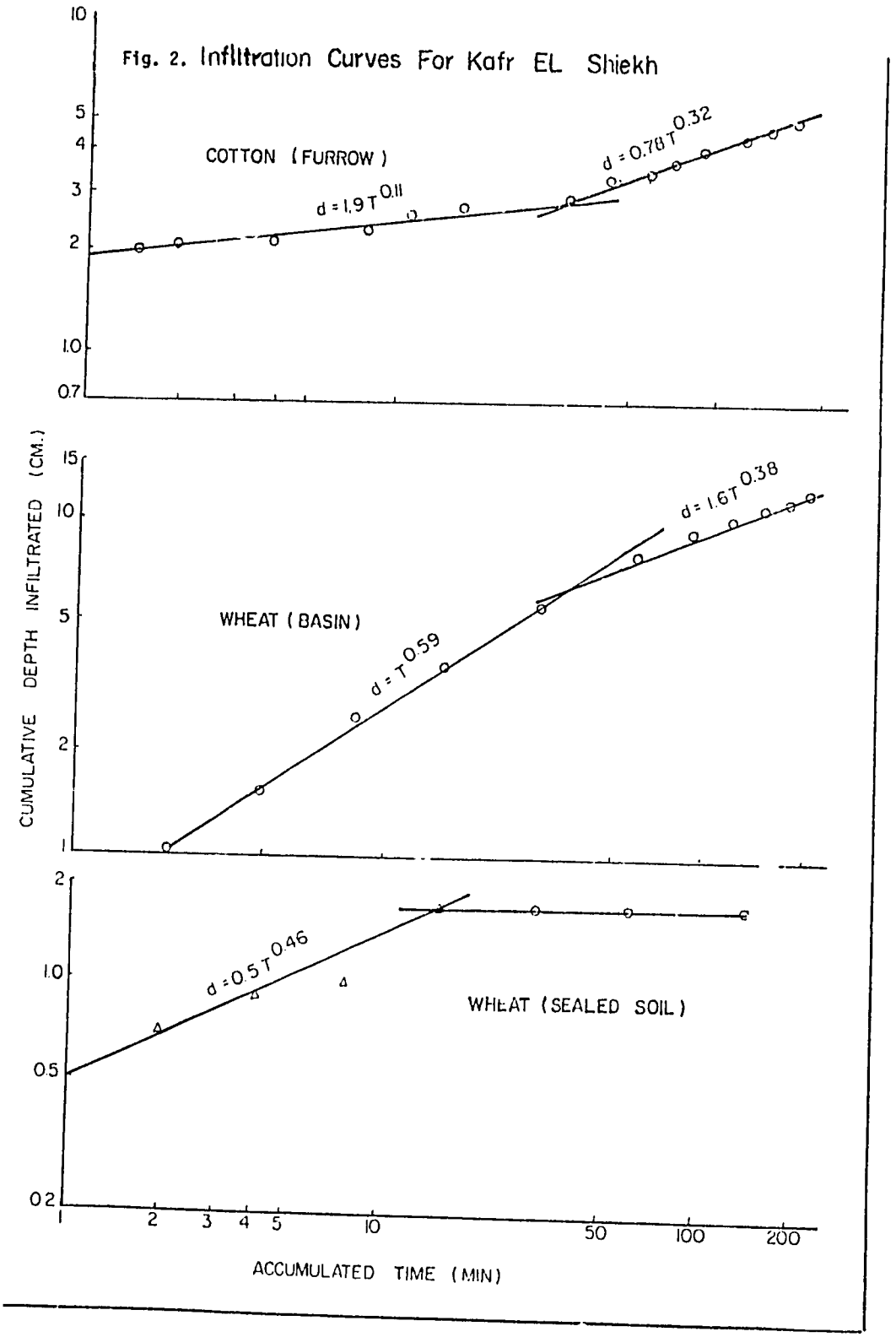
Fig. 2. Infiltration Curves For Kafr EL Shiekh
COTTON (FURROW)
d = 1.9 T^0.11
d = 0.78 T^0.32
WHEAT (BASIN)
d = T^0.59
d = 1.6 T^0.38
WHEAT (SEALED SOIL)
d = 0.5 T^0.46
CUMULATIVE DEPTH INFILTRATED (CM.)
ACCUMULATED TIME (MIN)
10
5
4
3
2
1.0
0.7
15
10
5
2
1
2
1.0
0.5
0.2
1
2
3
4
5
10
50
100
200

Fig. 3 Detailed Soil Water Analysis Mansurya

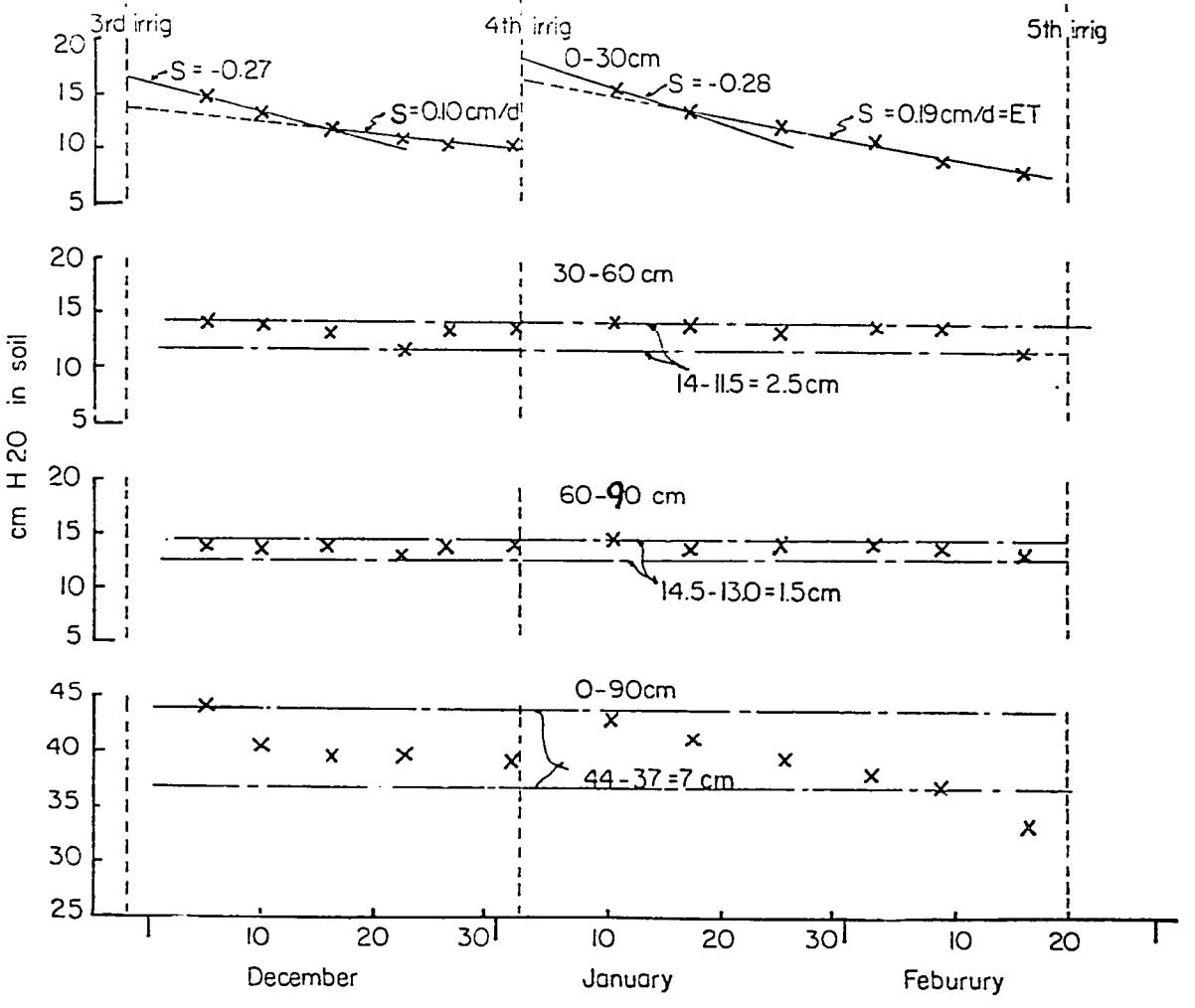

Table 2. Changes of soil water volume and aeration in Vertisols in Egypt.

Depth (cm)		1st irrigation		2nd irrigation		3rd irrigation		4th irrigation		5th irrigation	
		before	after	before	after	before	after	before	after	before	after
0-15	water	29	59	33	57	41	66	41	60	41	58
	air	25	Sat.	21	Sat.	14	Sat.	13	Sat.	15	Sat.
15-30		33	53	45	58	47	62	55	59	53	54
		17	Sat.	5	Sat.	3	Saturated				
30-60		43	47	46	58	54	58	56	69	52	59
		3	Saturated								

Root penetration. Associated with the limited depth of water movement is the root penetration (Table 3). In repeated sampling, root penetration is limited in the upper 30 cm of the soil profile, but rarely did the 90% root recovery exceed the 40-50 cm layer. This limited root penetration is dramatically demonstrated every fall when the farmers remove their cotton stalks by simply pulling them up intact after a heavy post harvest irrigation, as well as root pruning in sugarbeet.

Operational available water. The net result of the limited root development and soil water changes being concentrated in the upper 30 cm, is the operationally available water which is limited to 5-7 cm for most crops (Table 4). This amount of water is substantially less than would be expected from the Vertisols in Egypt.

In a system in which water has only a nominal charge, farmers are willing to irrigate when the agronomic returns to the water are small. The irrigation system, therefore, needs to be capable of providing water in 5-7 cm increments, a volume which is rather difficult for a surface irrigation system to accommodate.

The drawback is that with this low operational available water, which is less than the irrigation system can successfully provide, a water table build-up can be expected and frequently occurs with every irrigation (Fig. 4).

With the frequent occurrence of a water table (Table 5), surface drainage is desirable. Such drainage has shown substantial crop response (Fig. 5).

Table 3. Index of root penetration in Egyptian Vertisols.

Depth (cm)	Cotton		Maize			Berseem		Wheat	
	Minya	KeS	Minya	KeS	Mans	Minya	KeS	Minya	KeS
	Acc. % Recovered								
0-10	66	73	60	90	87	77	77	44	53
10-20	85	93	81	98	94	82	84	48	59
20-30	92	98	87	99	96	84	86	86	67
30-40	95	99	92	100	97	86	92	89	80
40-50	98	100	100		99	89	98	95	96
50-60	99				100	94	99	97	98
60-70						96	100	99	99

Table 4. Operational available soil water for a Typic Torrert in Egypt.

Crop	cm H_2O/90 cm soil			
	Irri	Before	After	Dif.
Sugarcane	16	45	51	6
Wheat	7	46	51	7
Cotton	9	45	51	6
Berseem	7	40	45	5
Wheat	5	42	48	7
Sugarbeet	6	41	48	7
Cotton	6	40	47	7
Maize	8	42	47	5

Table 5. Monthly average depth to water tables for Typic Torrerts in Egypt.[a]

Location	1981									1982			
	Apr.	May	June	July	Aug.	Sept	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
	cm below surface												
El-Minya	177	108	-	149	120	137	125	146	159	179	-	191	175
Kafrel-Sheikh	68	79	47	26	30	37	55	71	68	73	62	59	72

[a]Adopted from EWUP Water Budget.

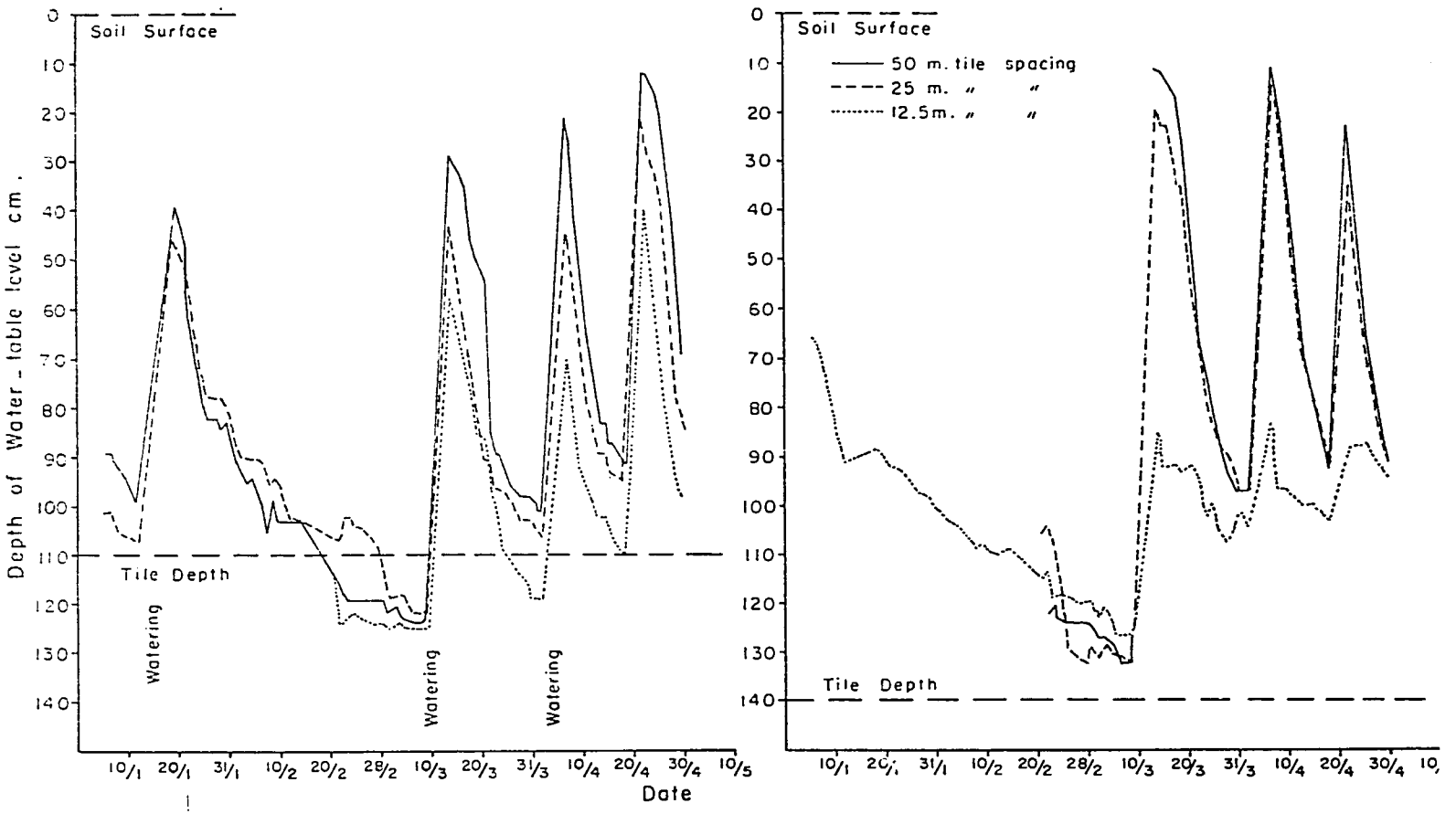

Fig. 4. Fluctuation of Water-table (Wheat 1980/81) Sakha.

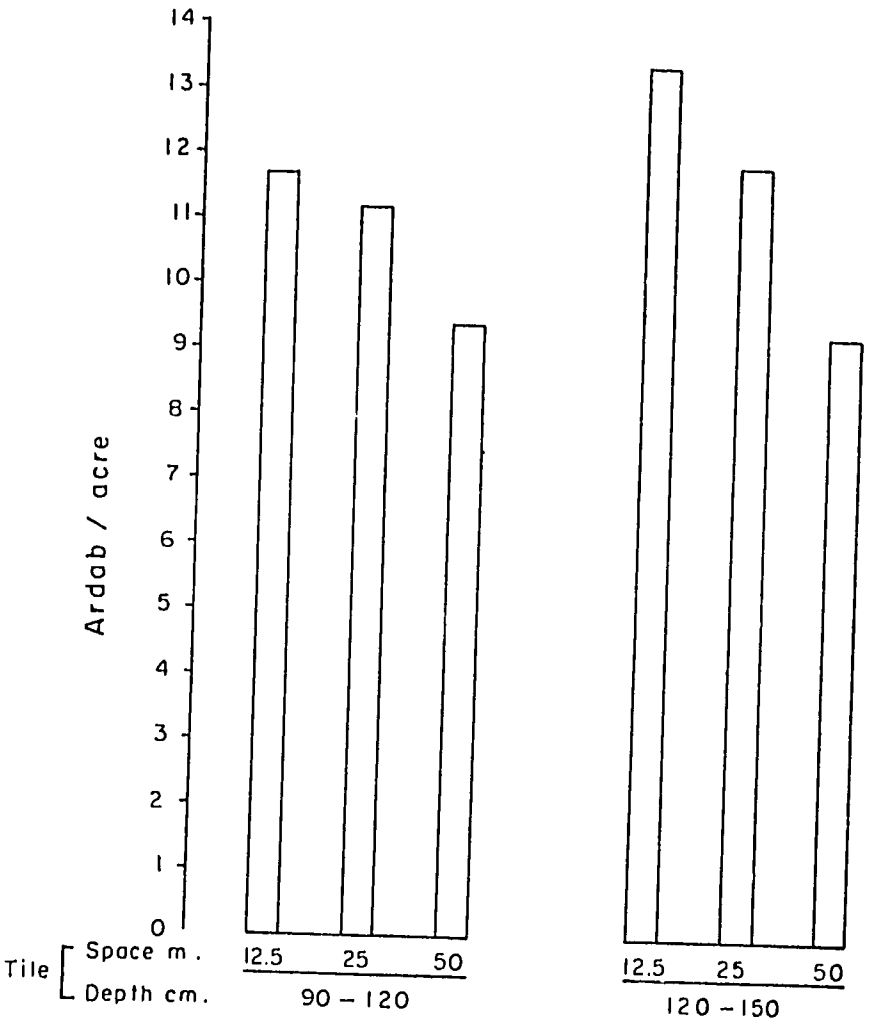

Fig. 5. Wheat yield as affected by field tile drainage (1981)

CONCLUSIONS

To overcome these problems, certain predictions should be adopted which may solve them to a great extent.

1. Water in Egypt is provided for the farmers free of charge; therefore, lifting is recommended to put a nominal in-kind charge on the farmers to encourage soil and water conservation.

2. Fields are plowed too dry, forming large clods and roughness of the surface. The traditional way of irrigating these soils is to cover completely the soil surface. This will contribute to the rise of water table level.

3. The inadequate drainage system should be replaced. There exists currently a sound and effective program of providing tile drains throughout the whole country.

4. The small irrigation channels should be lined to minimize seepage.

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THE RELATIONSHIPS BETWEEN SOIL CLASSIFICATION AND NATIVE PLANT PRODUCTION AND COMPOSITION ON ARIDISOLS AND RELATED SOILS

D.T. Pendleton and T.N. Shiflet

Aridisols are soils that do not have water available for mesophytic plants for long periods. Most of the time when the soil is warm enough for plants to grow, water is held at a tension ≥ 15 bars. Generally, there is no period of three months or more when moisture is continuously available and the soil is warm. The surface horizon or horizons are normally light in color. Pedogenic horizons may be the result of translocation and accumulation of salts, carbonates, or silicate clays or cementation by carbonates or silica; or may be an alteration of parent materials without significant accumulation. The temperature regime ranges from cryic to isohyperthermic, and the moisture regime is usually aridic. Much of the soil surface is usually bare. If gravel is present, desert pavement usually forms (Soil Conservation Service, 1975).

Most areas of Aridisols and related soils[1] in the United States are best suited and managed to produce native vegetation used mainly for grazing and browsing by ruminant animals. Such lands are known in the United States as rangeland. The climax or natural potential vegetation is predominantly grasses, grasslike plants, forbs, or shrubs (Soil Conservation Service, 1976). Species composition and production are the result of soil, climate, topography, and, to a lesser degree, fire, floods, insects, and grazing use by indigenous herbivores. These lands are not routinely cultivated, irrigated, fertilized, or mechanically harvested. Management is by ecological principles rather than agronomic practices and is achieved principally through the manipulation of grazing animals. Environmental factors such as soil depth, slope, moisture-holding capacity, salt content, rocks, and climate limit the use of most rangeland for more intensive agricultural enterprises. Grazing and browsing by herbivores is the most practical and often the only means of converting range vegetation into food, fiber, and other desirable products. Were it not for the unique ability of ruminant animals to gain nutrition from range roughage, the vegetation would be a wasted resource.

Range production on Aridisols and related soils, though low on a unit-area basis, is nevertheless important in the United States because of their great extent. Range grazing produced 213 million animal unit months of forage for domestic livestock each year in the 1970's, the equivalent of almost 18 million animal units on an annual basis. This was about 15% of all roughage consumed by livestock in the United States (Forest Service, 1980). About 99% of range forage is produced in the 17 western states, west of the 100th meridian, where Aridisols and related soils are prevalent.

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[1] In this paper, related soils include Torriorthents and Xerorthents from the Order Entisols, and Xerolls from the Order Mollisols.

ENVIRONMENTAL FACTORS AND CLIMAX PLANT COMMUNITIES

Basically, three environmental factors interact to produce climax vegetation. They are soil, climate, and topography.

Soil

Soil is the major physical component of the ecosystem, is relatively permanent, and its characteristics are less readily altered by past use and treatment than is vegetation (Anderson, 1968).

Since Aridisols and related soils occupy such a large area of diverse topography and climate, plant production and composition differ drastically from place to place. At the soil order, suborder, and great group level, relationships between soil, plant species composition, and production are tenuous at best. A special study conducted by Passey et al. (1982) for the Soil Conservation Service (SCS) documents these relationships in the Great Basin of the United States. The study was conducted primarily in a mesic temperature regime and aridic and xeric moisture regimes. Precipitation ranged from 200 to 400 mm, but at most study locations was 200 to 230 mm. The data represents 298 transect years. Table 1 shows that average annual production on aridisols ranged from 512 kg/ha on Xerollic Natrargids to 829 kg/ha on Xerollic Calciorthids. Among Mollisols, the differences were even greater. For example, average annual production ranged from 560 kg/ha on the Aridic Calcic Argixerolls to three times that amount (1,664 kg/ha) on the Typic Argixerolls.

At the soil order, suborder, and great group level, species composition showed no patterns of value for management (Table 2). Bearded bluebunch wheatgrass (AGSP-*Agropyron spicatum*) occurred on 59 of 85 study sites and was the highest producing grass on 29. It was dominant on Aridisols and many Mollisols in this climatic regime. Beardless bluebunch wheatgrass (AGIN-*Agropyron inerme*) was present on 27 of 85 sites and was the highest producer on 22. It did not occur on the Aridisols, Natrixerolls, or Durixerolls in this study but strongly preferred the other Xerolls and the Entisols. Idaho fescue (FEID-*Festuca idahoensis*) occurred only on Mollisols and grew on all great groups except Calcixerolls.

Many plants showed no preference of soils. Sandberg bluegrass (POSE-*Poa secunda*) grew on 83 of 85 study sites, but was never a high producer. Likewise, the exotic annual cheatgrass (BRTE-*Bromus tectorum*) grew well on all soils except the Natrargids. Two forbs, Hoods phlox (PHHO-*Phlox hoodii*) and longleaf phlox (PHLO2-*phlox longifolia*) grew on all soil great groups.

In the study, soil subgroups provided the most meaningful level of soil classification for correlation with broad plant associations. The presence of different species or subspecies of sagebrush, *Artemisia* spp., provided the most meaningful grouping of plant communities.

Basin big sagebrush (ARTRT-*Artemisia tridentata* ssp. *tridentata*) grew on 26 study sites but preferred the Calcixerolls (Table 2). Wyoming big sagebrush (ARTRW-*Artemisia tridentata* ssp. *wyomingensis*) was common on the Aridisols and to a lesser degree, the Haploxerolls and Durixerolls. On the other hand,

Table 1.--Percentage of cover and average annual production by soil taxonomic groups.
[Adapted from Passey et al., 1982]

Soil				No. of Plots	Plot Years Yield Data	Average (Pct.)			Average Annual Production (kg/ha)				
Order	Suborder	Great Group	Subgroup			Plant Cover	Stone Cover	Bare Ground	Annuals	Grass	Forbs	Shrubs	Total
Aridisols	Argids	Natrargids	Xerollic	2	15	9	2	75	4	213	94	202	512
	Orthids	Camborthids	Ustollic	1	1	28	0	47	T	380	29	184	593
			Lithic Xerollic	2	20	13	61	17	13	350	190	115	663
			Xerollic	3	4	11	11	62	8	547	33	185	773
		Calciorthids	Xerollic	2	20	15	15	58	65	407	139	219	829
Entisols	Orthents	Torriorthents	Xeric	1	10	19	3	61	19	746	111	63	939
Mollisols	Xerolls	Natrixerolls	Aridic	1	2	11	11	63	1	204	146	366	717
		Calcixerolls	Aridic	2	20	18	13	53	13	621	142	200	975
			Typic	5	10	17	3	47	27	772	316	227	1,342
		Haploxerolls	Lithic	3	14	11	29	40	23	309	211	264	807
			Calciorthidic	8	37	16	3	60	23	456	194	158	831
			Calcic Pachic	1	1	18	2	58	T	552	312	92	956
			Cumulic	1	4	9	8	59	156	39	619	318	1,132
			Calcic	2	4	18	9	41	26	759	230	143	1,158
			Pachic	3	4	24	3	21	53	901	727	425	2,135
		Argixerolls	Aridic Calcic	1	1	16	59	21	T	259	19	282	560
			Lithic	1	2	9	51	30	15	106	496	67	684
			Calcic	13	36	20	8	52	76	630	153	235	1,053
			Calcic Pachic	2	12	21	3	48	30	813	119	123	1,085
			Aridic	1	2	16	2	57	17	679	248	181	1,125
			Pachic	7	21	20	2	39	54	841	392	225	1,152
			Typic	2	2	15	9	57	42	631	881	111	1,664

Table 2. Percentage of microplots in which individual plant species occur, by soil taxonomic groups.

Species	Entisols		Aridisols		Mollisols						
	Orthents	Argids	Orthids	Average	Xerolls						Average
	Torri	Natr	Calci and Camb		Natri	Calci	Haplo	Argi	Pale	Duri	
Grasses											
AGSP	0	65	90	85	30	32	48	31	16	81	40
AGIN	80	0	0	0	0	64	20	35	33	0	25
FEID	0	0	0	0	30	0	31	52	48	38	33
POSE	90	88	92	91	100	94	72	96	98	90	92
BRTE	70	0	34	27	10	38	40	26	42	25	30
Forbs											
PHHO	80	20	32	30	95	16	6	8	17	5	25
PHLO2	25	68	55	58	45	61	39	48	45	85	54
Shrubs											
ARTRT	25	0	0	0	0	37	8	17	15	0	13
ARTRW	0	68	59	61	0	0	23	0	0	19	7
ARTRV	0	0	0	0	0	0	0	13	0	0	2
ARTR4	0	3	0	1	0	0	4	5	1	1	2

(Adapted from Passey et al., 1982)

mountain big sagebrush (ARTRV-*Artemisia tridentata* ssp. *vaseyana*) grew only on Argixerolls, and threetip sagebrush (ARTR4-*Artemisia tripartita*) was most prevalent on the Argixerolls and Haploxerolls.

On similar soils in the thermic and hyperthermic temperature regimes, one might expect creosotebush (*Larrea tridentata*), tarbush (*Flourensia cernua*), certain species of *Acacia* and *Prosopis*, and some cactus-like plants rather than the *Artemisias*.

Climate

Climate, like soil, has a significant effect on plant composition and production. Precipitation, temperature, and elevation affecting climatic influences are particularly important. Within relatively small geographical areas, climate may be uniform and apply to all plant communities. Over broad areas, however, the plant community changes along climatic gradients (Shiflet, 1972). When such gradients occur on uniform slope and topography, the change from one plant community to another is gradual.

Most research shows a positive relationship between production and annual precipitation as well as precipitation for selected periods. In the study by Passey et al. (1982), the correlation between total annual production and total annual precipitation was significant (at the .05 level) on only two soils, Goodington and Bancroft (Table 3). And there was a strong correlation (.01 level) between total production and precipitation for the period April 1 through June 30 on three soils: Trevino, Roseworth, and Neeley. Although the production/precipitation relationships in the study were positive, they were too broad to provide precise indices. Total annual production in the climax plant communities studied was too erratic for development of worthwhile production indices from precipitation data alone.

Large variations in plant composition also are common from year to year. On Abela gravelly loam (an Aridic Calcixeroll), production of beardless bluebunch wheatgrass, the most consistent producing grass, ranged from 804 kg/ha and 70% of the composition in 1958 to 339 kg/ha and 40% of the composition in 1965 (Passey et al., 1982).

Topography

Topography also plays an important role in determining the climax plant community. Slope, exposure, and landscape position affect runoff and run-on of water, evaporation, temperature, and other factors. Often, similar soils support different vegetation because of the influence of topography.

An example from Passey et al. (1982) is Trevino extremely stony silt loam (a Lithic Xerollic Camborthid). This soil occurs on both north- and south-facing slopes. Plant communities were similar on both slopes. Over a ten-year period, however, average production was 103 kg/ha greater on the north-facing slope.

Table 3. Coefficients of correlation between total annual production and periods of precipitation for eight selected soils

Study Location and Soil Units[a]	Average precipitation from rain gages			
	Total Oct. 1–Sept. 30	Oct. 1–June 30	Oct. 1–March 31	April 1–June 30
CAREY KIPUKA				
Goodington sil.	0.764[b]	0.722[b]	0.326	0.577
Clegg sil.	0.584	0.321	0.0	0.0
Bancroft sil., mod. deep over bedrock variant	0.778[b]	0.562	0.259	0.620
LITTLE CRATER KIPUKA				
Trevino ex. st. sil.	0.0	0.0	0.0	0.976[c]
Roseworth sil.	0.272	0.0	0.0	0.955[c]
Neeley sil., deep over bedrock variant	0.0	0.363	0.0	0.796[c]
KOTTLE BUTTE KIPUKA				
Brunt sil., heavy subsoil var.	0.327	0.214	0.0	0.715[b]
Pancheri sil.	0.0	0.0	0.0	0.0

(Adapted from Passey et al., 1982)

[a]Texture symbols are from Soil Survey Manual, USDA Agric. Handbook 18, 1951.

[b]Significant at .05 level.

[c]Highly significant at .01 level.

Thus, soil properties modify the effect of climate on the distribution and production of individual plants and as members of plant communities. Conversely, variations in weather conditions apparently modify or mask the effect of specific soil properties on plant growth and distribution. While the relationships among soil, climate, and vegetation are rather vague and general at the soil order, suborder, and great group level, the correlation is much more refined at the family, series, and phase level (Heerwagen and Aandahl, 1961). Distinct plant communities occur on similar soils within areas of uniform environment (Shiflet, 1972). Distinctively different communities seldom occur on the same phase of a soil series under the present system of soil classification.

RANGE SITES

Because of the intricate interactions between soil, climate, and topography, range classification procedures used by SCS are based on vegetation, the product of the total environment. SCS used these and other environmental factors as a basis for developing the range site and condition concept (Dyksterhuis, 1949; Renner and Allred, 1962; and Shiflet, 1973). This concept, like all good resource inventory techniques, enables the user to compare the current status of the resource to the site potential (Passey and Hugie, 1962). The range site and condition procedure was devised for management purposes. It has been evolving for more than 30 years and has been widely accepted.

A range site is a distinctive kind of rangeland that differs from other kinds of rangeland in its ability to produce a characteristic climax plant community (Soil Conservation Service, 1976). It is capable of supporting a native plant community typified by an association of species differing from those of other range sites in kind or proportion of species or in total annual production. Differences must be significant enough to require different management.

Differentiating range sites

Table 4 illustrates how plant community data are used to arrive at range site groupings. Average productivity and species composition are shown. Obviously, all three soils support essentially the same climax plant community. All are dominated by bluebunch wheatgrass with only minor differences in the other species, but the Manila soil is approximately 17% more productive than the Broad. If such a difference affects management, the Manila and Broad plant communities would be placed in separate sites, and the Middle plant community would be placed with the one it most closely resembles, since its productivity is not significantly different from the other two. If the difference in production has no significance for management, all three would be grouped into a single range site.

Three other stands studied for ten years in the Great Basin project are compared in Table 5. The only major environmental difference in the three study locations was the soil. Production from the Hoelzle and Bancroft

soils did not differ significantly, but their plant communities were 35% more productive than those of the Goodington soil. This difference was statistically significant and obviously large enough to require different management. The Goodington plant community, therefore, would be separated from the other two because of lower productivity. The other two stands did not differ in production but did differ in species composition. Idaho fescue was a higher producer on the Hoelzle soil than on the Bancroft.

The major difference in the two plant communities was the shrub component. Big sagebrush, though minor, was the major shrub in the Hoelzle community but did not occur in the Bancroft. On the other hand, threetip sagebrush accounted for only 2% of the vegetation produced on the Hoelzle soil but was the most important shrub on the Bancroft soil, contributing 17% of the total production. On the basis of lower productivity in the Goodington community and differences in species composition and proportion of species between the Hoelzle and Bancroft communities, it was concluded that all three were unique and represented three distinct range sites.

If all rangeland supported climax vegetation, classification into range sites would be simple. However, since climax stands of vegetation no longer exist for many sites, these stands must be reconstructed by interpolation and extrapolation of available plant community data. Soil information plays the major role in extending existing data to similar environmental situations and to points along environmental gradients where usable data are not available.

Table 4. Average production, composition, and frequency of vegetation produced on three soils in Box Elder County, Utah.[1]

Major Species	SOIL TAXONOMIC UNITS					
	Middle		Broad		Manila	
	Prod (kg/ha)	Comp (%)	Prod (kg/ha)	Comp (%)	Prod (kg/ha)	Comp (%)
Bluebunch wheatgrass	1650b[2]	85	1462a	82	1833b	88
Sandberg bluegrass	32	2	58	3	24	1
Balsamroot	50	3	34	2	7	T
Cheatgrass	9	T	7	T	1	T
Yellowbrush	32	2	64	4	36	2
Big sagebrush	29	1	32	2	30	1
Bitterbrush	44	2	-	-	1	T
Other species	92	5	116	7	140	8
Totals	1938ab	100	1773a	100	2072b	100

(Adapted from Shiflet, 1972)
[1]Based on 30 observations of 10 subplots each.
[2]Production values in the same horizontal line followed by the same letter were not significantly different at the 5% probability level.
T = Trace percentage (less than 0.5%)
- = Did not occur or does not apply.

Table 5. Average production, composition, and frequency of vegetation produced on three soils in Blaine County, Idaho.[a]

Major Species	SOIL TAXONOMIC UNITS					
	Goodington		Hoelzle		Bancroft	
	Prod (kg/ha)	Comp (%)	Prod (kg/ha)	Comp (%)	Prod (kg/ha)	Comp (%)
Idaho fescue	187	24	430	39	257	24
Bluebunch wheatgrass	62	8	121	11	159	15
Sandberg bluegrass	144	18	149	13	91	9
Squirreltail	94	12	41	4	-	-
Prairie junegrass	13	2	6	1	84	8
Narrowleaf pusseytoes	43	5	-	-	-	-
Longleaf phlox	31	4	19	2	26	3
Hawksbeard	-	-	9	1	47	4
Balsamroot	-	-	8	1	-	-
Other annuals	55	7	38	3	11	1
Big sagebrush	25	3	67	6	-	-
Threetip sagebrush	11	1	21	2	175	17
Desert rabbitbrush	14	2	17	2	27	3
Other species	114	14	177	15	166	16
Totals	793a	100	1103b	100	1043b	100

(Adapted from Shiflet, 1972)

[a]Based on ten annual observations of 20 subplots each.

T = Trace percentage (less than 0.5%)

· = Did not occur or does not apply

Using range sites to map rangeland does not eliminate the need for soil surveys on these lands. Soil scientists and range conservationists work together to design map units. If soils and vegetation are properly correlated and mapped within a soil survey area, range site delineations can be taken directly from the soil map.

The delineation of a soil series does not automatically delimit a unique climax plant community or a range site. Turner et al. (1974), in the Soil Survey of Lea County, New Mexico, identified 36 soils. Similarity of the plant communities on many of the soils resulted in the recognition of but only 12 range sites based on their climax vegetation. In the Gila-Duncan area of Arizona, six soil series are grouped into the Limy Upland Range Site, 7 to 12-inch precipitation zone (DeWall, 1981). Three or more series per range site is quite common.

All site descriptions are considered approximations, subject to change when more and better data become available.

RANGE CONDITION

Range sites are the basic ecological units into which the rangeland landscape is divided for study, evaluation, and management. The site expresses capability or potential. Range condition, on the other hand, is an ecological rating of the present plant community. It expresses the relative degree to which the kinds and proportions of plants in the present community resemble that of the presumed climax plant community for the site. Changes in the plant community may either increase or decrease the value of the site for various uses. An abnormal amount of any species, regardless of value, represents a change in condition. Thus, range condition reflects past management and enables the range scientist to predict the direction and extent of change likely to occur in response to specific treatment or management (Pendleton, 1982).

Four range condition classes are used by SCS to express the degree to which present plant composition resembles that of climax. These classes are excellent, good, fair, and poor. Some agencies use a variation of condition in which five classes are recognized.

USE OF RANGE SITE AND CONDITION IN RANGE MANAGEMENT

The major use of range site and condition is to provide an inventory for range management purposes. Decisions regarding management are based on this inventory and the landuser's objectives. Areas to reseed and species to use can be identified. Key grazing areas within each grazing unit and key species on which to base utilization are also determined. The inventory is a basis for determining stocking rates, season of use, and kind and class of grazing animals required to achieve objectives. It also indicates the need for fencing, water developments, and other conservation practices.

Trend in range condition (toward or away from climax) is normally determined at the time range sites are mapped and condition is determined. This information provides a basis for any adjustment deeded in present management. Subsequent evaluations of trend are used to measure the effectiveness of applied management and to adjust it further if necessary.

Much research and many field studies have also been based on range sites and condition. McCorkle and Heerwagen (1951) assessed the effect of site and condition on livestock production in the plains area of New Mexica and Colorado. They found on the predominant site (Upland Plains) that good, fair, and poor condition ranges averaged 16.0, 12.5, and 10.0 kg/ha of beef, respectively. Ir Kansas, three range sites were used to study the effect of various burning treatments on Flint Hills rangeland (Anderson et al., 1970). Holland (1971) found that a decrease of one condition class resulted in the doubling of sediment delivery. Cox and Cole (1960) used range site as the basis for specifying species and seeding rates for range seeding in South Dakota. Numerous studies have been reported comparing the production and quality of forage between sites and between condition classes within a single site.

Most government agencies and educational institut ns in the United States now use the range site and condition concept, or a variation of it, for range resource inventory, study, and management. In fact, the use of range site and condition has spread to other countries and continents (Abercrombie, 1974; Fulton et al., 1978).

Although range site is based on the climax plant community, climax or excellent range condition is not always the management goal. Often a condition below the potential provides benefits more useful to management objectives and still provides adequate resource conservation. For example, a range site in fair or good ecological condition may be a better habitat for some wildlife species than the same site in excellent condition.

SUMMARY

Relationships between soil classification and vegetation are uncertain at the soil order, suborder, and great group level. At the family, series, and phase levels, however, the relationships become increasingly predictable. Distinct plant communities occur on similar soils within areas of uniform environment. Distinctively different plant communities seldom are found on the same phase of a soil series under the present system of soil classification. Soil is the major physical component of the range ecosystem. In addition to soil, climate and topography are factors that strongly influence climax vegetation. Using these three parameters, SCS developed a range site and condition classification scheme in which vegetation, the product of the total environment, is the controlling factor. Range site expresses potential, and range condition compares the present plant community to the potential for the site. This procedure has evolved over many years. It is useful for study, evaluation, and management of rangeland vegetation. It provides a basis for explaining the effects of past management and for predicting likely responses to different management strategies. The range site and condition methodology has become widely used in the United States and in some other countries and continents.

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THE INTERNATIONAL BENCHMARK SITES NETWORK FOR AGROTECHNOLOGY TRANSFER

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In the next 20 years the world will have to feed two billion more people. Although there exist the land resources and the technology to produce enough food for this anticipated population, there is considerable doubt as to whether the food will be produced where it is needed most and distributed in an equitable manner.

Ironically, food shortages of major proportions are expected to arise among the agrarian countries of the tropics and subtropics where the major part of the as yet unexploited or underutilized resources of arable land of the world are located. Advantageously, however, the knowledge about the management of these resources for the production of food and fiber has dramatically increased in recent decades through the work of the national and international agricultural research centers. But the work of these research centers becomes meaningful only when the results can be effectively conveyed to the ultimate user--the farmer--in all areas where they are environmentally and sociologically applicable. It is distressing, therefore, that the development of operational methodologies for the efficient diffusion of agroproduction technology has lagged behind the knowledge generation process. Research and development efforts relative to the transfer of agrotechnology must consequently be augmented so that the existing and rapidly expanding knowledge base can be shared by many users in the countries of the Third World. This is particularly crucial for countries which lack the capital and human resources to set up national research programs or cannot delay their agricultural development until their own research has yielded implementable results.

In the context of this perspective, the International Benchmark Sites Network for Agrotechnology Transfer, IBSNAT, has been established to develop and test a methodology for integrating scientific and technological knowledge of agricultural production into systems that optimize resource management and facilitate the transfer of technology in the tropics and subtropics.

IBSNAT is an outgrowth of the Benchmark Soils Project of the universities of Hawaii and Puerto Rico and has had a long gestation period. The idea of the network was first discussed at a workshop on "Operational Implications of Agrotechnology Transference Research" held at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in October, 1978. Another milestone in the project development was an international panel consultation on the "Strategy for Land Evaluation and Agrotechnology Transfer in the Tropics and Subtropics" which was hosted by FAO in Rome in March, 1980. IBSNAT has recently been funded, in part, by the United States Agency for International Development (AID) under a one-year contract with the University of Hawaii.

The University of Hawaii will serve as the coordinating entity and as a catalyst for IBSNAT. The ultimate success of the project, however, will depend on the aggregate research output resulting from the concerted efforts by the various collaborators who in their entirety form IBSNAT. Through the aspired synergistic collaboration of institutions from many countries, IBSNAT holds the promise of emerging as a major scientific endeavor of multidisciplinary nature and international scope of consequence to the agricultural development in the lower latitudes.

The purpose of this paper is to give an overview of IBSNAT and its underlying rationales. As the project has only been effective for a short time, complete operational details have not been finalized and this discussion will, therefore, be confined to the overall project design. We want to make it clear at the outset, however, that IBSNAT concerns primarily the transfer among countries and between regions within countries, i.e. horizontal transfers. The diffusion of technology to farmer fields, i.e. vertical transfer, has been deliberately excluded from the scope of IBSNAT. Consequently, this paper will address mainly horizontal transfers which should not be construed to imply that the crucial importance of vertical transfers is not recognized.

PROJECT RATIONALES

Approaches to agrotechnology transfer

Uehara (1981) defined agrotechnology transfer as the taking of an agricultural innovation from its site of origin to a new location where it is likely to succeed. How, then, are the innovations transferred from one location to another?

Most commonly transfer of agrotechnology occurs through trial and error, but there also exist scientific approaches. Swindale (1980, 1981), drawing in part on the work of Nix (1968, 1980), has identified three different, but not mutually exclusive, models.

Simulation models. Simulation models employ systems analysis to reduce the complex system into a number of simpler components and to identify the linkages between them in an attempt to mimic the behavior of the complex system (Nix, 1980).

Inherently simulation models should provide the best methodology for agrotechnology transfer. But the incompleteness of scientific knowledge, particularly relative to the cause and effect relations that control genotype-environment interactions, and the complexity of the models themselves have been barriers to their use. The difficulty in achieving the multidisciplinary collaboration that is clearly required to develop the models may have been a further detriment (Swindale, 1980).

As Nix has pointed out, however, the development of simulation models is essential to identify the "minimum data set" needed for the adequate interpretation and extrapolation of experiment results. This minimum data set consists of a cultivar-specific, balanced set of soil-crop-weather-management data and is, in turn, a key prerequisite for technology transfer via simulation models.

Statistical relationships. In this approach, correlations and multiple linear regressions are used to relate crop yields to input and resource variables. This site-factor method is widely used, but works better with interpolations rather than extrapolations and thus appears to be of limited value for intercountry transfers (Swindale, 1980).

Analogue transfer. Soil and climate classifications are used in this method to identify analogous areas. The assumptions are (i) that the taxa of the classification schemes stratify the environment with sufficient precision to ensure successful transfers, and (ii) that all occurrences of a defined class have similar production potentials and responses to management. While general, multi-attribute schemes of agroclimatic classification are of limited value in the analogue transfer of technology (Burgos, 1968), soil classifications have been more successful. The U.S. system, Soil Taxonomy (Soil Survey Staff, 1975), is particularly suited for this purpose as it incorporates both soil and climate and thus stratifies the agroenvironment into distinct niches of agroproduction (Beinroth, 1983).

Transfer by analogy is also implied in the concept of benchmark soils advanced by Kellogg in 1961. As currently defined, a benchmark soil is an important soil selected for intensive study and complete characterization because it occupies a key interpretative position in the classification and/or covers large areas (Miller and Nichols, 1980). A benchmark soil represents a reference site from which research results can be extrapolated to other areas with similar characteristics.

Role of soil classification in agrotechnology transfer

Soil scientists have long assumed that soil classification, in conjunction with soil surveys, provides an adequate basis for the transfer of pedologic knowledge and agronomic experience. Many authoritative statements can be found in the literature which allude to this conjecture. In the foreword of the FAO-UNESCO Soil Map of the World (FAO, 1974), for example, it is stated that one of the objectives of the map was "to supply a scientific basis for the transfer of experience between areas with similar environments . . . (because) . . . with the tremendous amount of knowledge and experience gained in the management and development of different soils throughout the world, the hardship perpetuated in some areas by methods of trial and error is no longer justified." And Smith (1965) pointed out that "we make the basic assumption that experience with a particular kind of soil in one place can be applied to that particular kind of soil wherever it exists if consideration is taken of any climatic differences."

The stated assumptions and the transfer hypothesis implied therein were subjected to a thorough scientific test in the Benchmark Soils Project (BSP) of the Universities of Hawaii and Puerto Rico whose primary objective was to test the transferability of agroproduction technology on the basis of soil families as defined in Soil Taxonomy. The results of the BSP (Benchmark Soils Project, 1982a and 1982b) show that Soil Taxonomy taxa allow to predict crop production potential and management requirements in qualitative terms and that, logically, the specificity of predictions increases with decreasing categoric levels. The extensive experimental and statistical work conducted by the BSP also showed that fertilizer response and crop yields

can be predicted with considerable accuracy at the family level if additional site factors are taken into consideration (Benchmark Soils Project, 1982a).

The importance of this provision has also been emphasized by Smith (1981) who, in his last technical paper, wrote that "soil interpretations at any categoric level nearly always require an additional step of reasoning which includes the relation between the potential use being considered and the soil properties. This requires knowledge of soil and non-soil factors that cannot be inferred from the classification."

Ecosystems approach to agrotechnology transfer

In the light of the preceding, it should be obvious that a quantitative model of agrotechnology transfer must necessarily be more complex than the somewhat simplistic approach of analogue transfer that was tested by the BSP. The intricacy of the transfer process clearly calls for a holistic approach that should be based primarily on concepts of transfer by simulation.

Central to this approach is the realization that in successful transfers the characteristics and requirements of cultivars must be compatible with the environmental conditions at the new site. This implies (i) quantitative knowledge of the cause and effect relations between the soil, agroclimate, and management practices on the one hand, and crop requirements and performance on the other hand, and (ii) quantitative knowledge of certain environmental parameters of the transfer site.

The transfer model of IBSNAT has essentially four components:

1. Data base generation through site characterization, field experiments and growth chamber studies;

2. Data base management, particularly the development of computerized data bases which contain (a) pedon data, (b) climatic data, and (c) crop growth and development data collected in field and growth chamber studies;

3. Development of computer simulation models which employ the data bases above to produce predictions of crop growth and yield; and

4. Verification of predictions, adaptations of transferred technology, and diffusion of technology.

IBSNAT'S GOAL AND OBJECTIVES

The goal of IBSNAT is to maximize successes and to minimize failures in the transfer of high-performance cultivars and the technology required to exploit their genetic potential.

The principle objectives of IBSNAT are:

1. To develop and validate performance prediction models for important crops of the tropics and subtropics;

2. To design a methodology for determining the minimum data sets required for the effective transfer of agrotechnology; and

3. To devise a prototype telecommunication system for the transnational exchange and diffusion of agroproduction technology at a scientific level.

MAJOR IBSNAT ACTIVITIES

Network establishment

IBSNAT will consolidate a group of collaborating agricultural research centers in a prototype network for the purpose of generating the data base for the development of crop performance prediction models and testing their validity. This worldwide cluster should initially comprise about 20 actively cooperating National and International Agricultural Research Centers and Regional Research Organizations that are willing to financially and technically support the research effort and whose stations represent the dominant agroecological zones and the major kind of soils of the tropics and subtropics. Examples of the three kinds of desired collaborators are the Centro Nacional de Investigaciones Agropecuarias (CENIAP) of Venezuela, the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in India, and the Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD) in Syria, respectively.

Data generation

Data for IBSNAT will come from from detailed soil, climate and site characterization, and agronomic research. The latter will be conducted using specially designed experiments conducive to creating the data base needed for establishing the relationships between soil, climate and other site characteristics and crop requirements and performance under various levels of management inputs. This research should elucidate the genotype-environment interactions and will provide the data base that will enable the data analyzers to model agricultural production and management systems.

In the course of field experimentation, it will be essential to collect balanced sets of soil-weather-crop-management data that monitor the whole crop system and facilitate the identification of minimum data sets. Data compilation should be characterized by a wide range and a high precision, accuracy, and frequency of measurements and observations.

The crops currently under consideration for model development and/or validation include cacao, cassava, coffee, cotton, groundnuts, maize, pigeon

peas, plantain, potatoes, rice, sorghum, soybeans, and wheat. Other root crops may be added. To the extent feasible, it is planned to grow all crops under study at all appropriate sites of the network. This will allow the establishment of the boundary conditions of environmental crop requirements under a wide range of soil and climatic situations.

Not all of the crops mentioned will require the same amount of research. User-oriented models for maize and wheat, for example, are already available for field validation. For some of the crops, growth-chamber studies are contemplated to complement the field experiments.

Data management

In recent years, scientists in many countries have developed models to simulate various agricultural processes. One of the most comprehensive operational models has been devised by scientists of the USDA Agricultural Research Service working, in collaboration with the USDA Soil Conservation Service, in Temple, Texas. This model is called the Erosion-Productivity Impact Calculator (EPIC) and is designed to simulate the long-term change in yield resulting from changing soil properties due to wind and water erosion. The eight major components of EPIC include hydrology, weather, erosion, nutrients, plant growth, soil temperature, tillage, and economics. By simulating the interactions of these components, the EPIC model can produce long-term estimates of soil depth, soil nitrogen and phosphorus levels, crop yield trends, and the effect of erosion on soil loss and yield.

Other important models developed at Temple simulate grain yields of maize and wheat for a single growing period. The major inputs of these models include daily weather, water-holding capacity of the soil, soil fertility, applied fertilizer, and crop cultivar. The interactions of these components result in predicted dates of plant development stages, leaf area, and dry matter and grain yields.

Recognizing the immense potential of simulation models, the USDA is currently developing a general agricultural management model called Agricultural Land Management Alternatives with Numerical Assessment Criteria, ALMANAC. This model is a synthesis of the models mentioned above.

ALMANAC is designed for use in decision-making and in research. It allows decision-makers to evaluate the effects of various management options. It simulates the effects of different tillage practices on soil physical and chemical properties and the effects of various conservation practices such as terraces and windbreaks on wind and water erosion, and it simulates different irrigation techniques and the effect of water tables and impermeable layers on root and crop growth. ALMANAC also simulates nitrogen and phosphorus fertility and their effect on crop growth. The versatility of ALMANAC allows comparisons among crops with different nutrient requirements, among soils with different native fertilities, and among sites with different weather characteristics.

Individual farmers can use ALMANAC to plan their farm operation to increase profit, conserve soil, and provide a cleaner environment. Watershed and river basin managers will find ALMANAC quite useful for determining

optimal management for large areas. And ALMANAC will be useful at regional and national levels for making policy decisions.

In addition to decision-making capabilities at various levels, ALMANAC also provides two modes of operation for long- and short-term assessments. Short-term or within growing season decisions are facilitated by simulating crop growth at weekly intervals during the growing season. Early in the season, such decisions are based mainly on probabilities of weather conditions for the remainder of the season. Decisions become clearer, however, as the crop grows simply because observed conditions are substituted for uncertain conditions at each weekly simulation run.

Long-term decisions are based on computer simulations for 25 to 100 years. These simulations provide probability distributions that can be used for (i) making annual decisions like crop varieties and fertilizer rates, or (ii) making long-term decisions like structural measures for erosion control. The long-term simulations are also essential in studying the effects of erosion on productivity because erosion can be a relatively slow process.

The soil, weather, and crop data generated by the IBSNAT collaborators will be used to adapt ALMANAC to the agroenvironmental conditions of the tropics and subtropics. In the modelling process it will be attempted to relate crop performance to named kinds of soil, following the criteria and nomenclature of Soil Taxonomy. This approach is based on the realization that the numerical value of an individual soil parameter is meaningful only in relation to other soil properties and that the effect of a given parameter on soil behavior varies with the taxonomic class of a soil.

The final model must be operational and user-oriented and must allow long-term predictions and assessments. To meet these requirements, it must employ minimum data sets that are devoid of nonessential information. This implies, in turn, that the data base must be compiled, analyzed, and interpreted in a way that is compatible with the model. If this is assured, computers can perform the complex task of matching crop requirements with the site factors at the transfer location in a fast and sophisticated way. For example, using historical weather data for a 20-year period, a weather simulator can predict 50 years of statistically similar weather. On the basis of this and other site factors critical for a specific land use, the model should be able to predict crop yields, or any other output, and display it as a frequency distribution for a 50-year period. This will allow the user to judge the risk associated with unfavorable weather conditions. It may be of interest to note that present computer technology permits the operation of such simulation programs at the speed of one second computer time per crop year, or less than one minute for a 50-year run.

The simulation models will be experimentally validated at IBSNAT collaborator sites and observed discrepancies will provide useful feedback for refining the basic model. It is also planned to test the sensitivity of the model by using only Soil Taxonomy-derived data for various categoric levels. The purpose of that study is to determine how accurate crop performance predictions are if they are based only on the information contained, by definition, in the name of a taxon and on the covariant accessory properties.

Information dissemination

As this aspect will become more important in the later stages of the project, particulars have not been developed at this time. It is clear, however, that all of the data collected at the IBSNAT sites will, with the permission of the responsible institution, be available to other members of the network. It is also intended to develop a user-friendly query-response interface program for minicomputers through which the data base and computing capacity of a mainframe computer can be accessed.

Symposium on minimum data sets for agrotechnology transfer

IBSNAT's first major activity will be an international symposium on "Minimum Data Sets for Agrotechnology Transfer." This symposium is co-sponsored by ICRISAT, IBSNAT and the Soil Management Support Services (SMSS) of the USDA and will be held at ICRISAT in Hyderabad, India, from March 21 to 26, 1983. Participants at the symposium will be mainly the data generators representing the agricultural research centers collaborating with IBSNAT and data managers. The purpose of the symposium is to reach a consensus among the collaborating institutions, agencies, and organizations regarding the crops to be studied, the kind and design of the field experiments to be conducted, the nature and magnitude of the soil, weather, management, and crop phenological data to be collected and to discuss data processing, analysis and interpretation, and dissemination of information.

The symposium will provide a forum for the participants to create a network that functions for the mutual benefit of all collaborating institutions. It will also allow the collaborators to actively participate in the planning and design of IBSNAT. The ICRISAT symposium will be the first in a series of meetings designed to convene the collaborators periodically to report progress on attainment of network objectives and to plan future work.

IBSNAT LINKAGES

By intent and design, IBSNAT depends heavily on the cooperation of experts in many fields and efforts will therefore be made to enlist the best available individual talents and institutions in this joint endeavor.

IBSNAT will be able to draw on the expertise and institutional capabilities of other AID-supported projects, notably the Soil Management Support Services of the USDA Soil Conservation Service and such programs as the Soil Management Collaborative Research Support Program (CRSP) or TROPSOIL, the Nitrogen Fixation by Tropical Agricultural Legumes project (NifTAL), and the International Soybean Program (INTSOY).

Mutually beneficial linkages are anticipated with FAO, the International Fertilizer Development Center, the National Oceanic and Atmospheric Administration of the U.S. Department of Commerce, the Foreign Agricultural Service of the USDA, the Federal Institute for Geosciences and Natural Resources of West Germany, and others.

CONCLUSION

IBSNAT's main premise is that agrotechnology transfer can be achieved by simulating the performance of cultivars and management practices at the transfer site. To demonstrate the feasibility of this approach, IBSNAT will consolidate a cluster of national and international agricultural research centers into a prototype network for the purpose of developing, testing, and utilizing a scientific methodology for the effective transfer of agrotechnology that is based on a systems approach and computer simulation techniques.

While simulation models have long been considered the conceptually best approach, various constraints have prevented their use in the past. Advances in crop modelling, however, coupled with advances in computer technology, now make such an approach entirely feasible. Hugh amounts of data can now be processed quickly and translated in a purposeful way into user-oriented formats.

At the end of the nine-year project, the prototype IBSNAT network should transform into expanding and self-sustaining networks. At that time, each participating country should have the capability of screening large numbers of technologies and cultivars relative to their suitability for transfer to various agroecological zones of the country. The screening of technologies and cultivars by computer simulation cannot replace field research, but it enables the user to identify the technologies which, through a minimum of adaptive research, can be tailored to local conditions with a high probability of success.

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LABORATORY METHODS AND DATA EXCHANGE PROGRAM FOR SOIL CHARACTERIZATION (LABEX);

A SUMMARY OF THE REPORT ON THE PILOT ROUND

L.P. van Reeuwijk and W.G. Sombroek

ABSTRACT

To gauge the need for possible standardization of analytical procedures used for soil characterization and classification, twenty laboratories from all over the world analyzed ten "reference" samples on particle size distribution and cation exchange capacity. The analytical results in general show a large variability both in accuracy and precision, which are dependent on type of soil and laboratory. This strongly points to the need for standardization of analytical procedures. The results also indicate that such standardization is feasible but that a certain, not insignificant level of variability will remain unavoidable. Such estimated levels are (relative figures): ± 20% for CEC, ± 11% for clay determination and ± 25% for CEC of the clay. Consequently, classification criteria based on laboratory analyses should be used flexibly.

INTRODUCTION

Complying with the recommendations of the 2nd International Soil Classification Workshop held in Malaysia and Thailand in 1978, sponsored by U.S.A.I.D., the International Soil Museum at Wageningen initiated a program[1] for cross-checking, correlating, and possibly standardizing laboratory methods used for soil characterization in various parts of the world.

It was decided to start the program with a pilot round in which a limited number of laboratories would analyze a selection of divergent soils on some essential parameters. The results obtained in this round as well as future funding possibilities would be decisive for a possible continuation of the program in extending the number of participants, soil parameters to be analyzed and soil types.

All 22 invited laboratories, about half from "developed" and half from "developing" countries (see Appendix 2), accepted the invitation to participate and were supplied with 200 grams of 10 "reference" bulk samples prepared

[1] In cooperation with the Royal Tropical Institute, Amsterdam, the Netherlands.

by ISM[1] (see Table 1). They analyzed these samples on two parameters notoriously suspected to be dependent on the methods used, viz. particle size distribution and cation exchange capacity, according to their usual procedures.

A first progress report giving the results of 13 laboratories was presented at the 4th International Soil Classification Workshop, Rwanda, 1981. Now, the results of 20 laboratories are available and statistical treatment could be carried out.

MATERIALS AND METHODS

Soils

The soil samples selected as "reference" samples host a number of aspects relevant in soil characterization. Samples 1 and 2 (Ferric Acrisol/Oxic Paleudult) contain the argillic horizon aspect at relatively low clay content, whereas samples 6 and 7 (Humic Nitosol/Orthoxic Palehumult) have this at much higher clay content. Samples 3 and 4 (Rhodic Ferralsol/Typic Eutrustox) represent possible problems associated with Oxisols, such as CEC boundaries and dispersion difficulties. Samples 5 (Orthic Solonetz/Typic Natrargid) and 10 (Calcaric Fluvisol/Typic Fluvaquent) were included to represent solonetzic and calcaric soils respectively. Finally, an Andosol/Andept was selected in connection with both charge behavior and dispersion problems (samples 8 and 9). Bulk samples of about 75 kg of each "soil" were air-dried at about 20° C, mortar-crushed, and passed through a 2 mm sieve. Each sample was then very thoroughly mixed in a 200 litre container and transferred to 10 litre buckets for storage and dispensing.

Data processing

The methods used by the participating laboratories are given in Appendix 1. Only a few laboratories gave duplicate results of their analyses. In these cases, we averaged them for the present purpose.

Several laboratories gave particle size distribution data rounded off to whole figures. For uniformity we rounded off the data that were given with decimals except the silt values of samples 3 and 4 which appeared to be very low; rounding off would lead to relatively high deviations from the original values.

Unfortunately, the treatment of data was somewhat complicated by the fact that no agreement exists on the clay/silt boundary. Some laboratories call silt the fraction 2-50 µm (and consequently sand 50-2000 µm), whereas others take silt to be the fraction 2-20 µm (and sand 20-2000 µm); the majority determined both fractions, however. To do justice to the efforts of all laboratories and because of the wealth of data, it was decided to include both sets of data in the statistical treatment.

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[1] With the kind cooperation of the Kenya Soil Survey.

Table 1. Description of the reference samples.

No.	Location	Horizon	Depth (cm)	Classification
1.	Busia, Kenya	Ap	0- 15	Ferric Acrisol, petric phase/Oxic Pale(?)udult
2.		Bt2	50- 70	
3.	Magarini, Kenya	A[a]	0- 22	Rhodic Ferralsol/Typic Eutrustox
4.		B[a]	80-120	
5.	Bura-east, Kenya	A[a]	0- 20	Orthic Solonetz/Typic Natrargid
6.	Nairobi, Kenya	Ap	0- 18	Humic Nitosol/Orthoxic Palehumult
7.		Bt2	65-115	
8.	Kijabe, Kenya	Ah	0- 17	Mollic Andosol/Udic Eutrandept
9.		B[a]	75-105	
10.	Randwijk, Netherlands	C[a]	60-110	Calcaric Fluvisol/Typic Fluvaquent

[a]unspecified

In addition to the direct results of CEC and particle size distribution analysis, some derived parameters were calculated for practical purposes: firstly, the CEC of the clay, being a much used parameter in soil characterization and incorporating possible errors made in the CEC as well as in the clay determination, and secondly, the silt/clay ratio to underscore a major source of error in particle size analysis: the dispersion procedure. Aggregates of clay particles surviving pretreatment may largely be assigned to the silt fraction (and to the sand fraction, but this is not looked into here).

Statistical treatment of the data was performed using computer programs from the SPSS (Nie et al., 1975).

RESULTS AND DISCUSSIONS

In the present study we are dealing with two variables of which the significance has to be tested for each soil parameter:

1. Soils (soil sample difference)
2. Laboratories (different methods of analysis)

Soils

The analyses of variance of the data per soil (not given in this summary) indicate that for all parameters the soils are very significantly different (1% level), a goal that was aimed at by the selection of the samples. The horizontal columns "mean" in Table 2 give the average values of the parameters as they were determined by all laboratories. These values will be used as reference values in this study.

For the more important soil parameters (CEC, clay content, CEC-clay) a positive correlation was found between the error and the magnitude of the parameter. Therefore, the decision was made to perform the analysis of variance on the proportional (%) deviations from the mean, whereby the magnitude of the means is eliminated. In addition this gives a useful set of dimensionless data facilitating easy comparison of performances of laboratories. They are also presented in Table 2 (right-hand side).

The relative degree of difficulty of the soils is expressed by the relative magnitude of the standard deviations: the lower the values, the smaller the deviations from the mean. It appears that none of the soils is the easiest or most difficult in all parameters. Thus, soil 5 (Solonetz) appears to be the easiest in both the CEC and clay determination and hence in the CEC of the clay, but not in silt and sand. Soil 10 (Fluvisol) is the most difficult soil to determine the CEC of (calcareous!) while soils 8 and 9 (Andosol) are most difficult in the clay determination. The drying of this soil is probably responsible for a dispersion problem.

Calculation of the CEC of the clay often allows a rough check on the clay and CEC data (when the clay mineralogy is known). The most usual prominent error is probably the too-low estimate of the clay content leading to

TABLE 2.1 Analytical results and % deviation from the mean per soil.

CEC

Results (me/100g)

SOIL / LAB	Acrisol 1	Acrisol 2	Ferralsol 3	Ferralsol 4	Solonetz 5	Nitosol 6	Nitosol 7	Andosol 8	Andosol 9	Fluvisol 10
1	4.9	6.5	2.1	2.8	20.1	17.3	12.0	44.3	20.3	6.4
2	3.4	3.4	1.3	2.1	18.9	8.9	8.3	15.7	9.5	7.0
3	2.9	7.2	2.2	2.8	17.2	23.2	12.5	49.5	26.0	11.4
4	5.6	6.5	3.0	3.0	25.3	18.3	12.4	43.3	25.1	12.5
5	4.9	6.6	2.5	3.1	22.3	19.7	13.5	70.5	28.9	9.0
6	4.7	6.3	2.0	2.4	22.5	18.4	12.3	63.4	25.9	8.0
7	2.8	4.4	1.1	1.3	15.5	10.1	11.6	57.1	27.1	6.5
8	4.5	5.8	2.0	2.4	20.7	17.8	12.1	55.5	25.2	7.8
9	3.4	4.9	1.8	2.0	24.7	9.6	8.1	12.2	14.4	27.1
10	6.0	7.0	3.0	3.0	24.0	22.6	13.0	62.0	31.0	12.0
11	4.9	6.9	2.3	2.8	22.7	20.3	13.7	65.1	29.8	9.5
12	5.4	7.6	2.7	4.9	23.2	25.6	22.4	62.0	44.8	11.4
13	7.2	8.4	3.7	3.9	22.0	24.3	19.7	72.9	41.1	10.4
14	6.5	8.1	3.6	4.2	23.1	23.7	18.7	54.1	37.6	8.9
15	5.8	4.5	2.0	1.5	24.0	11.4	8.4	43.6	17.3	20.6
16	5.0	6.5	2.9	3.3	19.4	20.1	16.3	42.9	32.6	8.2
17	5.3	8.8	2.9	2.9	18.5	19.8	15.0	50.1	30.4	9.4
18	5.4	8.8	2.8	4.3	29.2	24.2	22.5	67.3	51.0	7.3
19	4.9	6.5	2.3	2.7	22.9	18.3	12.6	71.7	26.3	11.6
20	6.4	8.6	3.3	4.6	21.7	22.2	19.1	57.1	29.8	9.9
Mean	5.0	6.7	2.5	3.0	21.4	19.1	14.2	52.9	28.7	10.7

% Deviation

LAB	1	2	3	4	5	6	7	8	9	10	Mean
1	-2	-3	-16	-7	-6	-9	-15	-16	-29	-40	-14
2	-32	-49	-48	-30	-12	-53	-42	-74	-67	-35	-44
3	-42	7	-12	-7	-20	21	-12	-6	-9	7	-7
4	12	-3	20	0	18	-4	-13	-18	-13	17	2
5	-2	-1	0	3	4	3	-5	33	1	-16	2
6	-6	-6	-20	-20	5	-4	-13	20	-10	-25	-8
7	-44	-34	-56	-57	-28	-16	-18	8	-6	-39	-29
8	-10	-13	-20	-20	-3	-7	-15	5	-12	-27	-12
9	-32	-27	-28	-33	15	-50	-43	-77	-50	153	-17
10	20	4	20	0	12	18	-8	17	8	12	10
11	-2	3	-8	-7	6	6	-4	23	4	-11	1
12	8	13	3	63	8	34	58	17	56	7	27
13	44	25	48	30	3	27	39	38	43	-3	29
14	30	21	44	40	8	24	32	2	31	-17	22
15	16	-33	-20	-50	12	-40	-41	-18	-40	93	-12
16	0	-3	16	10	-9	5	15	-19	14	-23	0.6
17	6	31	16	-3	-14	4	6	5	6	-12	5
18	8	31	12	43	-6	27	58	27	78	-32	25
19	-2	-3	-8	-10	7	-4	-11	36	-8	8	0.5
20	28	28	32	53	1	16	35	8	4	-7	20

CLAY CONTENT

wt%

SOIL / LAB	1	2	3	4	5	6	7	8	9	10
1	14	13	7	24	28	34	47	4	10	15
2	14	25	17	36	26	76	85	27	10	16
3	20	30	14	38	36	74	84	16	24	24
4	16	28	16	37	29	74	85	16	31	18
5	21	31	17	37	32	81	90	39	36	26
6	14	26	15	36	29	72	82	20	7	17
7	16	28	17	40	31	79	88	26	13	18
8	17	27	17	39	31	66	82	16	2	15
9	14	26	14	34	30	62	76	6	8	18
10	13	23	10	34	25	55	70	11	14	15
11	14	25	17	39	28	72	85	16	7	16
12	19	30	19	40	31	80	89	55	59	20
13	12	25	15	36	28	29	63	8	3	7
14	16	28	18	40	30	52	51	28	23	18
15	12	24	12	25	26	47	46	8	5	12
16	17	27	18	38	30	66	76	25	21	18
17	16	25	14	36	27	74	89	18	26	20
18	15	26	14	34	31	78	87	1	10	20
19	13	23	15	38	25	73	85	18	6	14
20	15	26	16	41	30	77	86	16	9	14
Mean	15.4	25.8	15.1	36.1	29.2	66.1	77.3	18.7	16.2	17.1

% Deviation

LAB	1	2	3	4	5	6	7	8	9	10	Mean
1	-9	-50	-54	-34	-4	-49	-39	-79	-38	-12	-37
2	-9	-3	13	0	-11	15	10	44	-38	-6	2
3	30	16	-7	5	23	12	9	-14	48	41	16
4	4	9	6	2	1	12	10	-14	91	6	13
5	36	20	13	2	10	23	16	109	122	53	40
6	-9	1	-1	0	-1	9	6	7	-57	0	-5
7	4	9	13	11	6	20	14	39	-20	6	10
8	10	5	13	8	6	0	6	-14	-88	-12	-7
9	-9	1	-7	-6	3	-6	-2	-68	-51	6	-14
10	-16	-11	-34	-6	-14	-17	-9	-41	-14	-12	-17
11	-9	-3	13	8	-4	9	10	-14	-57	-6	-5
12	23	16	26	11	6	21	15	194	264	18	59
13	-22	-3	-1	0	-4	-56	-18	-57	-81	-58	-30
14	4	9	19	11	3	-21	-34	50	42	6	9
15	-22	-7	-21	-31	-11	-29	-40	-57	-69	-29	-32
16	10	5	19	5	3	0	-2	34	30	6	11
17	4	-3	-7	0	-8	12	15	-4	60	18	9
18	-3	1	-7	-6	6	18	13	-95	-38	18	-9
19	-16	-11	-1	5	-14	10	10	-4	-63	-18	-10
20	-3	1	6	14	3	16	11	-14	-44	-18	-3

CEC of the CLAY

me/100g

SOIL / LAB	1	2	3	4	5	6	7	8	9	10
1	35	50	30	12	72	51	26	1108	203	43
2	24	14	8	6	73	12	10	51	95	44
3	15	24	16	7	48	31	15	309	108	48
4	35	23	19	8	87	25	15	271	81	69
5	23	21	15	8	70	24	15	181	80	35
6	34	24	13	7	78	26	15	317	370	47
7	18	16	7	3	50	20	13	220	209	36
8	27	22	12	6	67	27	15	347	1260	52
9	24	19	13	6	82	16	11	203	180	151
10	46	30	30	9	96	41	29	564	221	80
11	35	28	14	7	81	28	16	407	427	59
12	28	25	14	12	75	32	25	113	76	57
13	60	34	25	11	79	84	31	911	1370	149
14	41	29	20	11	77	46	37	193	164	49
15	48	19	17	6	92	24	18	545	346	172
16	29	24	16	9	65	31	21	172	155	46
17	33	35	21	8	69	27	17	278	117	47
18	36	34	20	13	65	31	26	6730	510	37
19	38	28	15	7	91	25	15	398	438	83
20	43	33	21	11	72	29	22	357	331	71
Mean	33.6	26.6	17.2	8.3	74.4	31.4	19.0	683	337	68.6

% Deviation

LAB	1	2	3	4	5	6	7	8	9	10	Mean
1	4	88	75	40	-3	62	34	62	-40	-38	28
2	-28	-49	-56	-30	-2	-63	-49	-93	-72	-36	-48
3	-57	-10	-8	-11	-36	0	-22	-55	-68	-31	-30
4	4	-13	10	-3	17	-21	-23	-60	-76	1	-16
5	-31	-20	-14	1	-6	-23	-21	-74	-76	-50	-31
6	0	-9	-22	-20	4	-19	-21	-54	10	-31	-16
7	-48	-41	-62	-62	-33	-35	-31	-68	-38	-47	-46
8	-21	-19	-31	-26	-10	-14	-22	-49	274	-24	6
9	-28	-29	-25	-29	11	-51	-44	-70	-47	119	-19
10	38	14	75	6	29	31	-2	-18	-34	17	15
11	4	4	-21	-14	9	-10	-15	-40	26	-13	-7
12	-15	-5	-17	47	1	2	32	-84	-77	-17	-13
13	79	26	44	29	6	167	64	33	307	117	87
14	21	9	17	26	4	45	93	-72	-51	-28	6
15	44	-29	-3	-28	24	-23	-4	-20	3	150	11
16	-12	-9	-6	4	-13	-3	12	-75	-54	-34	-19
17	-1	32	21	-3	-8	-15	-11	-59	-65	-32	-14
18	7	27	17	51	-12	-1	36	884	51	-47	101
19	12	7	-11	-15	23	-20	-22	-42	30	21	-2
20	27	23	20	34	-3	-8	17	-48	-2	3	6

TABLE 2.2 Analytical results (cont'd).

SILT 1 CONTENT (2-20 µm)

wt%

SOIL / LAB	Acrisol 1	Acrisol 2	Ferralsol 3	Ferralsol 4	Solonetz 5	Nitosol 6	Nitosol 7	Andosol 8	Andosol 9	Fluvisol 10
1	19	28	5.0	7.4	11	29	24	31	33	21
2	17	17	0.9	1.3	9	12	7	34	33	21
3										
4										
5	16	16	1.0	1.0	9	9	4	38	50	23
6	19	20	2.0	2.5	13	18	12	48	49	22
7	19	19	0.7	0.7	11	11	6	45	52	23
8	17	16	0.1	0.3	11	20	11	50	31	24
9										
10	18	18	6.5	3.5	13	26	15	40	39	21
11	18	18	0.4	1.2	11	16	8	47	41	22
12	15	16	1.3	1.4	12	9	5	25	27	22
13	20	19	1.6	1.8	12	52	26	64	73	30
14	19	18	1.5	1.5	10	27	26	41	42	22
15										
16										
17										
18	21	19	2.0	1.0	12	12	7	2	51	23
19	20	16	1.3	1.5	15	15	9	37	55	17
20										
Mean	18.3	18.5	1.9	1.9	11.5	19.7	12.3	38.6	44.3	22.4

% Deviation

SOIL / LAB	1	2	3	4	5	6	7	8	9	10	Mean
1	4	52	157	283	-4	47	95	-20	-26	-6	58
2	-7	-8	-54	-33	-22	-39	-43	-12	-26	-6	-25
3											
4											
5											
6	-13	-13	-49	-48	-22	-54	-68	-2	13	3	-25
7	4	8	3	30	13	-9	-3	24	11	-2	8
8	4	3	-64	-64	-4	-44	-51	17	17	3	-18
9	-7	-13	-95	-85	-4	2	-11	30	-30	7	-21
10											-21
11	-2	-2	234	81	13	32	22	4	-12	-6	36
12	-2	-2	-79	-38	-4	-19	-35	22	-7	-2	-17
13	-18	-13	-33	-28	5	-54	-59	-35	-39	-2	-28
14	9	3	34	-7	5	164	111	66	65	34	48
15	4	-2	-23	-22	-13	37	111	6	-5	-2	9
16											
17											
18											
19	15	3	3	-48	[illegible]	-39	-43	-95	15	3	-18
20	9	-13	-33	-22	31	-24	-27	-4	24	-24	-8

SILT 2 CONTENT (2-50 µm)

wt%

SOIL / LAB	1	2	3	4	5	6	7	8	9	10
1										
2										
3	24	24	2.0	2.0	4	12	8	40	36	28
4	33	31	3.0	1.0	14	20	11	71	57	51
5	26	23	1.0	2.0	10	12	6	49	56	42
6	32	30	3.0	3.0	14	22	15	62	75	48
7	32	29	0.9	0.9	13	15	9	57	78	46
8										
9	30	22	2.0	4.0	8	16	8	40	40	42
10	34	29	7.0	4.3	14	30	17	50	56	45
11	30	28	0.8	2.0	13	20	11	61	54	44
12	30	29	2.2	2.1	16	13	8	36	34	49
13	33	30	3.4	2.6	13	63	36	78	88	53
14	31	27	2.0	2.0	13	34	37	53	57	47
15	33	30	4.0	16	17	42	35	50	33	46
16	28	28	1.5	1.4	12	24	20	52	67	40
17	30	32	1.0	1.0	13	18	7	67	62	53
18	35	30	2.8	2.4	14	15	10	73	69	49
19	31	30	5.9	2.6	15	19	10	61	76	45
20	31	28	0.8	0.6	13	16	11	69	83	49
Mean	30.8	28.2	2.5	2.9	12.7	23.0	15.2	57.0	60.1	45.7

% Deviation

SOIL / LAB	1	2	3	4	5	6	7	8	9	10	Mean
1											
2											
3	-22	-15	-22	-31	-69	-48	-48	-30	-40	-39	-36
4	7	10	18	-65	10	-13	-28	25	-5	12	-3
5	-16	-19	-61	-31	-21	-48	-61	-14	-7	-8	-28
6	4	6	18	4	10	-4	-2	9	25	5	8
7	4	3	-65	-69	2	-35	-41	0	30	1	17
8											
9	-3	-22	-22	39	-37	-30	-48	-30	-33	-8	-19
10	10	3	175	50	10	30	12	-12	-7	-2	27
11	-3	-1	-69	-31	2	-13	-28	7	-10	-4	-15
12	-3	3	-14	-27	26	-43	-48	-37	-43	7	-18
13	7	6	34	-10	2	174	136	37	47	16	45
14	1	-4	-22	-31	2	48	143	-7	-5	3	13
15	7	6	57	456	34	83	130	-12	-45	1	72
16	-9	-1	-41	-51	-6	4	31	-9	12	-13	-8
17	-3	13	-61	-65	2	-22	-54	18	3	16	-15
18	14	6	10	-17	10	-35	-34	28	15	7	0.5
19	1	6	132	-44	18	-17	-34	7	27	-2	9
20	1	-1	-69	-79	2	-30	-28	21	38	7	-14

SILT 1 / CLAY ratio

Ratio

SOIL / LAB	1	2	3	4	5	6	7	8	9	10
1	1.36	2.15	0.71	0.31	0.39	0.85	0.51	7.75	3.30	1.40
2	1.21	0.68	0.05	0.04	0.35	0.16	0.08	1.26	3.30	1.31
3										
4										
5	0.76	0.52	0.06	0.03	0.28	0.11	0.04	0.97	1.39	0.88
6	1.36	0.77	0.13	0.07	0.45	0.25	0.15	2.40	7.00	1.29
7	1.19	0.68	0.04	0.02	0.35	0.14	0.07	1.73	4.00	1.28
8	1.00	0.59	0.01	0.01	0.35	0.30	0.13	3.13	15.5	1.60
9										
10	1.38	0.78	0.65	0.10	0.52	0.47	0.21	3.64	2.79	1.40
11	1.29	0.72	0.02	0.03	0.39	0.22	0.09	2.94	5.86	1.38
12	0.79	0.53	0.07	0.04	0.39	0.11	0.06	0.45	0.46	1.10
13	1.67	0.76	0.17	0.05	0.43	1.79	0.41	8.00	24.3	4.29
14	1.19	0.64	0.08	0.04	0.33	0.52	0.51	1.46	1.83	1.22
15										
16										
17										
18	1.40	0.73	0.14	0.03	0.39	0.15	0.08	2.00	5.10	1.15
19	1.54	0.70	0.09	0.04	0.60	0.21	0.11	2.06	9.17	1.21
20										
Mean	1.24	0.79	0.17	0.06	0.40	0.41	0.19	2.91	6.46	1.50

% Deviation

SOIL / LAB	1	2	3	4	5	6	7	8	9	10	Mean
1	9	173	316	406	-2	109	170	167	-49	-7	129
2	-2	-14	-69	-41	-14	-61	-56	-57	-49	-13	-38
3											
4											
5											
6	-39	-35	-66	-56	-30	-73	-77	-66	-79	-41	-56
7	9	-3	-22	14	11	-39	-23	-17	8	-14	-7
8	-4	-14	-76	-71	-12	-66	-64	-40	-38	-15	-40
9	-19	-25	-97	-87	-12	-26	-29	8	140	7	-14
10											
11	12	-1	278	69	29	16	13	25	-57	-7	38
12	4	-9	-86	-49	-2	-45	-50	1	-9	-8	-26
13	-36	-32	-60	-43	-4	-72	-70	-84	-93	-27	-52
14	34	-4	1	-18	7	340	118	175	277	185	111
15	-4	-19	-52	-38	-17	28	169	-50	-72	-19	-7
16											
17											
18											
19	13	-7	-17	-52	-4	-62	-57	-31	-21	-23	-26
20	24	-12	-50	-35	49	-50	-44	-29	42	-19	-12

TABLE 2.3 Analytical results (cont'd).

SILT 2 / CLAY ratio

SOIL / LAB	Acrisol 1	Acrisol 2	Ferralsol 3	Ferralsol 4	Solonetz 5	Nitosol 6	Nitosol 7	Andosol 8	Andosol 9	Fluvisol 10
	Ratio									
1										
2										
3	1.20	0.80	0.14	0.05	0.11	0.16	0.10	2.50	1.50	1.17
4	2.06	1.11	0.19	0.03	0.48	0.27	0.13	4.44	1.84	2.83
5	1.24	0.74	0.06	0.05	0.31	0.15	0.07	1.26	1.56	1.62
6	2.29	1.15	0.20	0.08	0.48	0.31	0.18	3.10	10.7	2.82
7	2.00	1.04	0.05	0.02	0.42	0.10	0.10	2.19	6.00	2.56
8										
9	2.14	0.85	0.14	0.12	0.27	0.26	0.11	6.67	5.00	2.33
10	2.62	1.26	0.70	0.13	0.56	0.55	0.24	4.55	5.00	3.00
11	2.14	1.12	0.05	0.05	0.46	0.28	0.13	3.81	7.71	2.75
12	1.58	0.97	0.12	0.05	0.52	0.16	0.09	0.65	0.58	2.45
13	2.75	1.20	0.23	0.07	0.46	2.17	0.57	9.75	29.3	7.57
14	1.94	0.96	0.11	0.05	0.43	0.65	0.73	1.89	2.48	2.61
15	2.75	1.25	0.33	0.64	0.65	0.89	0.76	6.25	6.60	3.83
16	1.65	1.04	0.08	0.04	0.40	0.36	0.26	2.08	3.19	2.22
17	1.88	1.28	0.07	0.03	0.48	0.24	0.08	3.72	2.38	2.65
18	2.33	1.15	0.20	0.07	0.45	0.19	0.11	73.0	6.90	2.45
19	2.38	1.30	0.39	0.04	0.60	0.26	0.12	3.39	12.7	3.21
20	2.07	1.08	0.05	0.01	0.43	0.21	0.13	4.31	9.22	3.50
Mean	2.06	1.08	0.18	0.09	0.44	0.43	0.23	7.86	6.57	2.92

SOIL / LAB	1	2	3	4	5	6	7	8	9	10	Mean
	% Deviation										
1											
2											
3	-42	-26	-22	-42	-75	-62	-59	-68	-77	-60	-53
4	0	3	2	-70	9	-37	-44	-44	-72	-3	-26
5	-40	-31	-68	-40	-29	-66	-71	-84	-76	-45	-55
6	11	7	9	-8	9	-29	-20	-61	63	-3	-2
7	-3	-4	-71	-75	-5	-56	-55	-72	-9	-12	-36
8											
9	4	-21	-22	30	-40	-40	-54	-15	-24	-20	-20
10	27	17	282	39	26	27	6	-42	-39	3	35
11	4	4	-74	-43	5	-35	-44	-51	17	-6	-22
12	-23	-10	-37	-42	16	-62	-61	-92	-91	-16	-42
13	34	11	24	-20	5	405	149	24	347	160	114
14	-6	-10	-39	-43	-2	52	216	-76	-62	-10	2
15	34	16	82	606	48	108	231	-20	0	31	114
16	-20	-4	-55	-59	-10	-15	15	-74	-51	-24	-20
17	-9	19	-61	-69	9	-43	-66	-53	-64	-9	-35
18	13	7	9	-22	2	-55	-50	829	5	-16	72
19	16	21	114	-54	35	-39	-49	-57	93	10	9
20	0	0	-73	-84	-2	-52	-44	-45	40	20	-24

SAND 1 CONTENT (20-2000 µm)

SOIL / LAB	1	2	3	4	5	6	7	8	9	10
	wt%									
1	67	59	88	69	61	38	30	64	58	64
2	69	57	82	63	65	12	8	39	57	63
3										
4										
5	62	53	82	62	59	10	6	23	14	51
6	67	53	83	62	59	11	7	32	44	61
7	66	54	82	60	58	10	7	29	35	59
8	66	57	82	61	57	14	7	34	67	61
9										
10	68	56	83	61	57	11	6	31	31	62
11	68	56	83	61	61	13	7	38	53	62
12	66	54	80	59	57	11	6	21	14	58
13	68	56	83	62	60	19	11	27	24	63
14	64	55	81	59	60	21	22	31	36	60
15										
16										
17										
18	64	55	84	65	57	10	6	97	39	57
19	67	61	84	61	60	12	6	45	39	69
20										
Mean	66.3	56.0	82.8	61.9	59.3	11.8	9.9	39.3	39.3	60.7

SOIL / LAB	1	2	3	4	5	6	7	8	9	10	Mean
	% Deviation										
1	1	5	6	11	3	157	202	63	48	5	50
2	4	2	-1	2	10	-19	-19	-1	45	4	3
3											
4											
5	-6	-5	-1	0	-1	-32	-40	-41	-64	-16	-21
6	1	-2	0	0	-1	-26	-29	-19	12	0	-6
7	0	-4	-1	-3	-2	-32	-29	-26	-11	-3	-11
8	0	2	-1	-1	-4	-5	-29	-14	70	0	2
9											
10	3	0	0	-1	-4	-26	-40	-21	-21	2	-11
11	3	0	0	-1	3	-12	-29	-3	35	2	-0.2
12	0	-4	-3	-5	-4	-26	-40	-47	-64	-5	-20
13	3	0	0	0	1	20	11	-31	-39	4	-2
14	-3	-2	-2	-5	1	42	122	-21	-8	-1	12
15											
16											
17											
18	-3	-2	1	5	-4	-32	-40	147	-1	-6	7
19	1	9	1	-1	1	-19	-40	14	-1	14	-2
20											

SAND 2 CONTENT (50-2000 µm)

SOIL / LAB	1	2	3	4	5	6	7	8	9	10
	wt%									
1										
2										
3	56	46	82	60	60	14	8	44	40	48
4	51	41	81	62	57	6	4	13	12	31
5	53	46	82	61	58	7	4	12	8	32
6	54	43	82	61	57	7	4	19	18	35
7	53	44	82	59	56	7	4	17	9	36
8										
9	56	52	84	62	62	22	16	54	52	40
10	52	45	82	60	56	7	4	21	14	38
11	56	47	83	60	59	8	4	24	40	40
12	51	41	79	59	54	6	3	10	8	32
13	54	46	82	61	58	8	4	14	9	40
14	52	45	80	58	57	14	11	20	20	35
15	54	46	84	58	57	11	19	42	62	41
16	55	45	81	61	59	9	4	23	12	42
17	55	43	85	63	60	8	3	13	12	27
18	50	44	83	64	55	7	4	26	21	32
19	56	47	79	60	60	8	5	21	18	41
20	54	46	83	59	57	7	4	15	9	37
Mean	53.6	45.2	82.0	60.5	57.8	9.2	6.3	22.9	21.4	36.9

SOIL / LAB	1	2	3	4	5	6	7	8	9	10	Mean
	% Deviation										
1											
2											
3	4	2	0	-1	4	53	27	92	87	30	30
4	-5	-9	-1	3	-1	-35	-36	-43	-44	-16	-19
5	-1	2	0	1	0	-24	-36	-48	-63	-13	-18
6	[illegible]	-1	0	1	-1	-24	-36	-17	-16	-5	-10
7	-1	-3	0	-2	-3	-24	-36	-26	-58	-2	-16
8											
9	4	15	2	3	7	140	154	135	143	8	61
10	-3	-1	0	-1	-3	-24	-36	-8	-35	[illegible]	-11
11	4	4	1	-1	2	-13	-36	5	87	8	6
12	-5	-9	-4	-2	-7	-35	-52	-56	-63	-13	-25
13	1	2	0	1	0	-13	-36	-39	-58	8	-13
14	-3	-1	-2	-4	-1	53	75	-13	-7	-5	9
15	1	2	2	-4	-1	20	202	83	190	11	51
16	3	-1	-1	1	2	-2	-36	0	-44	-4	-6
17	3	-5	4	4	4	-13	-21	-35	-44	-27	-13
18	-7	-3	1	6	-5	-24	-36	13	-2	-13	-7
19	4	4	-4	-1	4	-13	-21	-8	-16	11	-4
20	1	2	1	-2	-1	-24	-36	-35	-58	0	-15

suspectly high values for the CEC of the clay. Also, the presence of organic matter leads to an overestimate of the CEC-clay. On the other hand, appreciable errors may not be conspicuous either because data seem to be within reasonable bounds or because they cancel out to a certain extent, e.g. a too-low clay estimate is compensated by a too-low CEC determination.

The present results show clear examples of all these features. The CEC of the clay of the Andosol (soils 8 and 9) in Table 2.1 is in many cases impossibly high even if the whole clay fraction would consist of allophane; at the same time the lowest CEC value found for soil 9 (lab 2: 9.5 me/100 g) coincides with a relatively low clay content (lab 2: 10%) yielding a CEC-clay of 95 me/100 g, a reasonable value for this type of soil.

Also, in soil 10 (calcareous Fluvisol) some impossibly high values of the CEC-clay occur, corroborating the malicious effect of carbonate on the clay determination (lab 13: -58% deviation from the mean) or on the CEC determination (lab 9: +153% deviation) or on both (lab 10, CEC: +12%, clay: -12%).

Yet, also in the many cases where errors are not conspicuous, wide variations in results within soils do occur. This is further illustrated by the silt contents and the silt/clay ratios. (Table 2.2, 2.3) where the latter particularly shows dispersion problems of the Andosol and Nitosol and also of the Ferralsol (although here the relatively low silt contents give a somewhat exaggerated picture).

As for the sand data, the agreement between the labs is striking (Table 2.3) for soils with high sand content (Acrisol, Ferralsol, Solonetz) but not so good for the clayey Nitosol. The Andosol is relatively "noisy" while the calcareous Fluvisol takes in an intermediate position.

This is a result of a negative correlation of errors in the sand determination with the magnitude of the sand content: sand as such is a relatively easy parameter to determine in contrast to clay and silt. The latter are more prone to errors and since the three parameters are complementary, higher clay and silt contents (with larger errors) are accompanied by larger errors in the sand determination.

Of more practical importance than the variability obtained by 20 laboratories together is the variability obtained by individual laboratories. This is discussed next.

Laboratories

An examination of the performance of individual laboratories has the important practical aspect that classification of a soil is nearly always based upon data of a single laboratory.

As expected, due to the very significant differences between soils, the analysis of variance of all data versus laboratories did not produce statistically significant differences between labs for any parameter. Therefore, as was done above, soil differences were eliminated by using the % deviations from the mean values of each soil.

In Table 2, the vertical columns "mean" on the right-hand side give the weighted means of the % deviations per soil and express the overall performance of each lab relative to the other.

To judge the performance of the individual laboratories two criteria have to be used: 1) the deviation of the lab mean from the "true" value (presently: the overall mean) should be as small as possible (good *accuracy*) and 2) the standard deviation or standard error of the lab should be as small as possible (internally regular data: good *precision*).

The use of the overall mean of the parameters as reference value in this study may somewhat comfort the laboratories with high deviations from this mean (low accuracy): improvements may be expected when standardization is accepted by all. As for the internal regularity of data (precision) it is uncertain if standardization will give similar improvements since this aspect is probably to a large extent a quality aspect of the individual laboratory.

According to the present results[1], the most "accurate" CEC values are produced by labs 4, 5, 11, 16, and 19 (near to the mean), while relatively good precision is shown by labs 1, 5, 10, 11, and several others.

Most accurate clay data are produced by labs 2, 6, 8, 11, and 20 on all soils and without the Andosol also by labs 9, 14, 16, 17, 18, and 19. The highest precision is obtained by labs 7, 10, and 16 on all soils and by a large number of labs when the Andosol is omitted.[2]

The CEC of the clay data show a much larger variability both in accuracy and precision. Accurate data are produced by labs 8, 11, 14, 19, and 20 on all soils and by some eight labs when the Andosol is omitted. The only precision below 10% error is achieved by lab 7 on all soils, whereas several labs show improved precision without the Andosol.

A few labs show reasonably good accuracy in the silt determination, but generally the accuracy is low as is the precision. By contrast, but as expected from the foregoing, the accuracy of the sand determination is good for several laboratories (2, 6, 8, 11, 13, 16, 18, 19) on all soils while the results are better still without Andosol. However, some other laboratories show remarkably low accuracy (1, 5, 9, 12, 15). The precision is generally disappointing.

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[1]After processing of the data, it was discovered that lab 10 produced its data on air-dry weight basis rather than on oven-dry basis. This has some implications for the clayey soils, the data of which have been underestimated. For good order, the respective moisture percentages as found by lab 10 for soils 1 to 10 are: 0.9 - 1.5 - 0.6 - 1.0 - 3.8 - 6.0 - 8.4 - 10.3 - 16.0 - 1.6.

[2]Lab 12 obtained exceptionally high clay contents (and thus low silt) for the Ando samples 8 and 9 due to a nonroutine effort to recover "all" clay (repeated agitation and decantation for several weeks). Although this was contrary to instruction, it casts an interesting light on the "true" value.

The data show that on the one hand there is reasonable to good agreement between several labs both in accuracy and precision (although these two do not necessarily coincide) but on the other, they reveal a disturbingly large variability in the mean values of laboratories as well as high internal inconsistencies.

Classification aspects

Table 2 allows some observations on classification aspects of the variability of the data. The soil with a CEC-clay requirement at the highest level of classification is the Ferralsol/Eutrustox. In all cases the oxic horizon (Table 2.1, CEC of the clay, soil 4) appears to have a CEC-clay < 16 me/100 g so that this soil seems to be a "safe" Ferralsol in this respect.

The Acrisol/Paleudult and the Nitosol/Palehumult have both been designated "ferralic/oxide" (c.q. the "kandic" of the ICOMLAC proposals) at subgroup level with the requirement that the CEC-clay < 24 me/100 g (by the NH_4OAc method). If the present B horizon is taken to have ferralic/oxic properties, then the Acrisol would not be designated as such by no fewer than ten laboratories (Table 2.1, CEC of the clay, soil 2) and the Nitosol by six laboratories (same Table, soil 7). Obviously, the original designation "oxic" was subjective in itself and may well be wrong, the discussion only focuses attention on the consequence of the variability in the data.

The Acrisol (soil 1 and 2) and the Nitosol (soil 6 and 7) are both Ultisols with the requirement for an argillic horizon. In case of the Acrisol, only one laboratory does not differentiate between the clay contents of the A and the B horizon to this end (Table 2.1, clay content, lab 1). In case of the Nitosol, only two laboratories (14 and 15) do not measure a sufficient clay increase (in fact, all three labs measure a lower clay content in the B horizon). However, several laboratories (2, 5, 7, 12, 18, 20) measured only 9% difference in clay content, just over the required minimum of 8%. Another 4 labs measured an increase of 10% or 11%. Considering the probability of an appreciable error in the clay determination (over 10% relative) in this case there can be quite some uncertainty on the reliability of data and chance plays a big role. Alternatively, this implies that by request of the person who classified the soil in the field, repeated analysis could well produce different data legitimately better suiting his classification.

Analysis of differences in analytical procedures

As was expected, a variety of methods was employed by the laboratories to determine the CEC and the particle size distribution (see Appendix 1). Also when the "same" method was used, details often varied, e.g. shaking time, leaching time. This strongly hampers the possibility of statistical treatment of data for significance of procedures. Since the collection of data do not result from an experiment with proper factor design, possible interactions of treatments are hard or impossible to analyze. Yet, an attempt was made to single out some of the most important method differences.

CEC. Six different CEC methods or groups of methods were compared. After elimination of soil influence by using % deviations from the mean values of each soil, the methods appeared to be very significantly different. The compulsive exchange method yields much lower CEC values than the other methods (44% below the mean) while the effective CEC method (ECEC) also yields relatively low values (-14%). The $CaCl_2$ pH 7 method yields the highest values (+10%). It is no surprise that the NH_4OAc pH 7 method yields results near to the mean since the majority of data was produced with this method.

The ECEC and compulsive exchange methods were individually tested against the other methods and both proved to give very significantly lower results than the other methods. It should be noted that of these methods, the data of only one laboratory each was available.[1]

Clay content. In the particle size analysis, several important pretreatments were applied by part of the laboratories and omitted by others.

The H_2O_2 treatment is omitted by about one-fourth of the laboratories. Analysis of variance shows no significant effect of this treatment. In fact, omitting it seems to have a positive effect. This casts doubt on the results and strongly suggests interaction with other effects.

Also one-fourth of the laboratories employ the decantation method to separate silt and clay from sand rather than use a sieve. With this method, less clay seemed to be found but the difference is statistically not significant.

Pretreatment to remove carbonate is routinely applied on all soils (also when carbonate is absent) by about one-third of the laboratories. Two different reagents are used, viz. the NaOAc pH 5 buffer and the HCl ph 3 solution. The mildly acid acetate buffer clearly gives the highest clay yield, whereas the HCl treatment yields less clay than when no treatment is given.

Three different types of physical dispersion are employed, viz. shaking by hand, mechanical shaking, and ultrasonic treatment, with the majority using mechanical shaking. Statistical analysis indicates no significant differences but the ultrasonic treatment appears to give some 10% higher clay content.

Finally, three methods of clay determination can be distinguished: the pipette method (employed by 15 labs), the hydrometer (4 labs), and the sedimentometer (1 lab). The hydrometer gives some 10% higher results than the pipette method (not statistically significant) whereas the sedimentometer gives significantly higher results (+40%).

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[1]The NaOAc pH 8.2 method was employed by one lab (3) on all soils and by another (12) on three soils. Since the results deviated only slightly from the mean (-7%), this method was taken up in the group "other methods."

CONCLUSIONS

The results obtained in this pilot round of a laboratory methods and data exchange program show that widely variable analytical results were obtained. Thus, if quantitative taxonomic systems for soil classification such as the FAO system or Soil Taxonomy are to be used globally, methods of soil analysis have to be standardized in detail. The present results indicate that such standardization is feasible but that probably relatively high minimum levels of variability have to be reckoned with. Consequently, taxonomic criteria for which these analyses are to be carried out have to be implemented flexibly.

From the present study, such minimum levels can be estimated at (relative figures): ± 20% for CEC, ± 11% for clay content, and ± 25% for CEC of the clay fraction.

RECOMMENDATIONS

Recommendations as to the choice of methods and details of procedures cannot be made at this stage. Such a choice has not only purely technical but also historical implications. A laboratory, quite satisfied with the procedure that has been in use for many years, might not be readily prepared to adapt. Further testing and correlation of methods by more laboratories seems to be the next step to take. The program also needs to be extended to other soil parameters such as base saturation, water dispersable clay, and others. Also, the present set of "reference" samples could be improved and perhaps extended to 15 or so. The dried Ando samples, although yielding useful information, appeared not to be representative for the present purpose. Interesting would be to include some "boundary" samples, e.g. between Ferralsol/Oxisol and Acrisol/Ultisol, and between Luvisol/Alfisol and Acrisol/Ultisol.

In any case, if work of this type is to have practical application and implementation, some policy-making committee should be set up. Suggestions for improvement and extension of the program are invited.

The full report, including the statistical treatment of data, can be obtained upon request from the International Soil Museum, Box 3543, 6700 AJ, Wageningen, the Netherlands.

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APPENDIX I.

CATION EXCHANGE CAPACITY (CEC) METHODS

Lab	Method	Sample weight	Saturating technique	Contact time	Procedure
1	NH_4OAc pH7	10 g (or 5 g)	leaching tube	5-6 hrs	2x50ml NH_4OAc pH7, 150ml 85-90% ethanol (final 30ml 95%). Then 2x50ml 0.1N K_2SO_4, NH_4 by distill. and titr.
2	Compulsive exchange	2 g	centrifuge tube	2 hrs	20ml .1M $BaCl_2$ (+ some NH_4Cl), 3x20ml .002M $BaCl_2$ (shake 1hr.). Then 10ml .005M $MgSO_4$, measure $MgCl_2$.
3	NaOAc pH8.2	2.5 g	eaching tube	1 drop/3sec	(100ml ethanol 75% if EC_{25}> 0.8mS/cm) 4x25ml 1N NH_4OAc pH7, 4x25ml NaOAc pH8.2, 100ml ethanol (1:1), 4x25ml NH_4OAc pH7, measure Na.
4	Sum of bases	10 g (?)	erlenmeyer	overnight	100ml 1N KCl: measure Ca & Mg by EDTA titration. 0.05N HCl + 0.025N H_2SO_4: K & Na flamephotometrically. 150 ml CaOAc pH 7, titrate with NaOH for (H + Al).
5	NH_4OAc pH7	5 g	leaching tube	> 1 hr	230ml 1M NH_4OAc pH7, 200ml ethanol. Then 230ml 1N NaCl. Distill for NH_4 by titration or autoanalyzer.
6	NH_4OAc pH7	5 g	filter funnel	2-24 hrs	(100ml ethanol 80% if EC_5>0.5mS/cm) 10x20ml 1N NH_4OAc pH7, 4x25ml ethanol 80%, 4x20ml 1N KCl pH2.5. NH_4 by autoanalyzer.
7	NH_4OAc pH7	5 g	leaching tube	1½ hr/100ml	100ml ethanol 1:1, 100ml 1N NH_4OAc pH7 /ethanol 1:1, 200ml 1N NaOAc pH7, 100ml ethanol 96%, 98 ml 1N NH_4OAc, measure Na.
8	NH_4OAc pH7	3-8 g	leaching tube (after Schollenberger)	4-24 hrs	100ml 1N NH_4OAc pH7, 50ml 80% ethanol, 100ml 10% KCl, distill for NH_4 by titration.
9	Effective CEC	5 g	centrifuge tube	2 hrs	30ml 1N NH_4OAc pH7 (repeat 2x), determine Na, K, Mg and Ca in supernatants. 30ml 1N KCl (repeat 2x), determine acidity by titration; Al by titration after addition NaF.
10	$CaCl_2$ pH7	20 g	filter funnel (?)	?	20x50ml 1N $CaCl_2$ pH7 (with TEA+HNO_3), 250ml .01N $CaCl_2$ (unbuff.), 1000ml 1N KNO_3, Ca by autoanalyzer.
11	NH_4OAc pH7	2.5 g	automatic extractor	overnight	extract with ca 70ml 1N NH_4OAc pH7, then 2x ca 70ml ethanol 95% (45 mins. each). Distill sample and titr. NH_4.
12	NH_4OAc pH7 & 8.2 and NaOAc pH8.2	?	centrifuge		details unknown.
13	NH_4OAc pH7	5 g	leaching tube	1½ hr/100ml	method virtually the same as lab 7.
14	NH_4OAc pH7	5 g	extraction bottle	overnight	30ml 1N NH_4OAc, filter on büchner funnel, 5x30ml 1N NH_4OAc, 2x30ml ethanol 95%, Distill sample, NH_4 by titr.
15	Effective CEC	10 g	extracting bottle	1 hr	100ml NH_4OAc pH7, filtrate. In extract measure Na, K, Ca, Mg. Make similar extract with 1N CaOAc pH7. Titrate for (H + Al).
16	NH_4OAc pH7	5 g	leaching tube	overnight	2x25ml 1N NH_4OAc pH 7 (overnight with 2nd 25ml), 100ml 95% ethanol, distill sample and titrate NH_4.
17	NH_4OAc pH7	5 g	leaching tube	?	5x20ml 1N NH_4OAc pH7, 8x20ml ethanol, distill sample and titrate NH_4.
18	NH_4OAc pH7	5 g	centrifuge tube	shake ½ hr stand 12 hrs	25ml 1N NH_4OAc, 5x25ml of same (shake 10 min.), 3x50ml propanol, 5x25ml propanol. Then 5x25ml 10% KCl, distill extract and titr. NH_4.
19	NH_4OAc pH7	25 g	erlenmeyer	overnight	50ml 1N NH_4OAc pH7, filtrate. Leach with 1N NH_4OAc pH7 until 250ml. Then 4x?ml 1N NH_4Cl, 1x .25N NH_4Cl, 2x small portions ethanol 80%, then 95% until leachate free of Cl^-. Distill sample and titrate NH_4.
	NaOAc pH8.2 (calc. soils)	5 g	centrifuge tube	5 min/wash	5x30ml 1N NaOAc pH 8.2, 4x30ml ethanol, 3x30ml NH_4OAc pH7, measure Na.
20	NH_4OAc pH7	10 g	erlenmeyer	overnight	250ml 1N NH_4OAc pH7, filtrate by büchner funnel (leach further until neg. test for Ca with NH_4oxal.). Then leach 2x with 1N NH_4Cl pH7, 1x with .25 of same, 150-200ml isopropylalcohol (Cl^-test!). Leach with acidified 10% NaCl (.005 HCl), distill leachate and titrate NH_4.

METHODS OF PARTICLE SIZE ANALYSIS

Lab	Sample[1] weight	H_2O_2[2]	Carbonate removal	Dispersing agent	High speed stirrer	Shaking procedure	Time	Separation silt & clay from sand[3]	Clay & silt determination	Remarks
1	10 or 20g	60ml 5%		5ml calgon 5% / 5ml 1N NaOH	15 min			decantation	pipette	
2	25 g	(option. McIntyre & Loveday '74)		5ml 1N NaOH + 10ml 10% Na-tripolyphosph. +200ml water		reciprocating (350 str./min)	16 hrs	decantation	pipette	
3	50 g			50ml calgon (overnight standing)		end-over-end	10 min		hydrometer	sand by diff.
4	50 g			25ml N NaOH (or calgon) overnight standing	15 min			53 µm sieve	hydrometer	sand by diff.
5	ca 20 g	3ml 30% pH 3.5[4]		12.5ml Na-polymetaphosph. 0.5-5 g/l		by hand + short mechanical		sieve	sedimentometer	sample preferably field-moist
6	10 ml	yes, in oven		10ml calgon 5% + 190ml water		stirring + ultrasonic	10 min	50 µm sieve	pipette	
7	20 g	30ml 15%	NaOAc pH5 (all samples)	25 ml 0.1N Na-pyrophosphate		reciprocating	16 hrs	50 µm sieve	pipette	
8	10 g	70 ml 8.5%		25ml 0.4 N calgon		mechanical	2 hrs	decantation	pipette	sand by wet-sieving
9	51 g			50ml 5% Na-hexametaphosph + 100ml water	15 min				hydrometer	sand by diff.
10	20 g	yes		40ml 4% Na-hexametaphosphate		rotating (40 r.p.m.)	4 hrs	siphon	pipette	
11	10 g	50ml water + few ml, repeat	NaOAc pH5 (opt.)	10ml 4% calgon		reciprocating (120 str./min)	16 hrs	300mesh sieve	pipette	shake 6 min before pipett.
12	?			Na-hexametaphosphate					pipette/succ. sedimentation	
13	20 g	75ml 20%	1N HCl/wash	10ml 5% calgon		by hand / mechanical	1 min	50 µm sieve	pipette	
14	52 g			10ml 17% calgon + 550ml water		mechanical 1 hr; next day 15 min			hydrometer	sand by diff.
15	10 g	25ml 30% (if O.M.>0.2%)		20ml 4.5% calgon + water to 300ml	15 min			no.70 sieve	pipette	sample oven-dry
16	10 g	method virtually the same as lab 11.								
17	10 g	50ml 10%, then 25ml 30%	170ml 0.1N HCl	Decant, 20ml $Na_4P_2O_7$ 0.8%, boil 5 min.				50 µm sieve	pipette	
18	20 g (pretreated)	Pretreat 50g with HCl pH3 (opt.) 6%		75ml 0.4 N $Na_4P_2O_7$ + water to 750ml		reciprocating (?)	6 hrs (leave overn.)	Pipetting, then wet-sieving of sand		If Fe_d 1%: dithionite treat
19	10 g	5ml 30%, wash and oven-dry		10ml 5% calgon, dilute to 300ml		reciprocating	6 hrs	300mesh sieve	pipette	
20	10 g	few ml 30%, wash and oven-dry		10ml 5% calgon, dilute to 180ml		reciprocating	16 hrs	50 µm sieve	pipette	

[1]air-dry fine earth unless otherwise stated.
[2]all with subsequent increments unless otherwise stated.
[3]sand by dry-sieving unless otherwise stated.
[4]unless carbonate is present.

APPENDIX 2.

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PROPOSED PROCEDURES FOR UPDATING SOIL TAXONOMY

Klaus W. Flach

The current procedures for updating Soil Taxonomy give inadequate recognition to international committees (ICOMS) and have not worked effectively. The proposed procedures are designed to remedy these shortcomings. An earlier version of these proposed procedures have been sent to chairmen of committees and other interested persons. Most of these comments have been received and will be considered in the development of the final procedure. The final procedure will be published in the publications listed under "Distribution of Approved Amendments."

PROPOSED COMMITTEE STRUCTURE

It is proposed to establish a policy committee which will make final decisions on changes in Soil Taxonomy and to recognize technical committees which will develop recommendations for the consideration of the policy committee.

1. The Soil Taxonomy Policy Committee

   Members: Directors of Soils, SCS, Chairperson
   National Leader (U.S.), Soil Taxonomy, as Secretary
   1 representative, U.S. Regional Technical Committees,
   1 representative, International Technical Committees,
   1 representative, Soil Taxonomy Committee, Soil Science Society of America

   Functions: To make final decisions on all changes in Soil Taxonomy above the series level.

2. Soil Taxonomy Technical Committees

   a. National and regional committees: Committees serving geographic areas which may be multinational, national, or regional (within nations).

      Members: Representatives of national, regional soil survey organizations and appropriate international groups.

   b. Subject matter committees: Committees that address taxa, groups of taxa, diagnostic criteria and other elements of Soil Taxonomy (e.g. ICOM's)

Members: Qualified soil scientists

c. Functions: National and regional or subject matter committees review proposals and develop and make recommendations to the Policy Committee for making changes in Soil Taxonomy. Technical committees and their chairpersons are recognized by the Soil Taxonomy Policy Committee. Committees develop their own rules concerning membership. Subject matter committees in the past have been open to all comers.

3. Ad hoc Committees and Referees

Functions: Similar to technical committees. The chairmen of ad hoc committees and referees are appointed by the Policy Committee to evaluate specific proposals or recommendations that cannot be handled by an existing technical committee.

PROPOSED PROCEDURES FOR MAKING CHANGES IN SOIL TAXONOMY

Anyone may propose changes in Soil Taxonomy. Proposal for establishment of an implied or parallel subgroup (see definitions below) will be handled as informally as possible. A more complex procedure is proposed for other changes.

Proposal for implied or parallel subgroups

Implied subgroups are subgroups that are excluded from the definition of the typic subgroup but for which no subgroup (intergrade or extragrade) has been recognized. Parallel subgroups are subgroups (or elements of the definition of the typic subgroup) that are recognized in one great group but not in an equivalent other great group.

Proposals should be addressed to the policy committee. If a national or regional technical committee has been established for the county or region from which the proposal originates, it should concur in the proposal. The policy committee will either approve the proposal or assign it to a referee or a technical committee for a recommendation. Proposals of this kind should be processed with a minimum of delay.

Proposals for other changes

Proposals should be addressed to the chairman of a technical committee or they may be sent to the secretary of the policy committee. If the proposal is submitted to the policy committee, it will be referred to an appropriate technical committee or the policy committee will appoint an ad hoc committee or a referee to evaluate the proposal and make a recommendation for its disposal. The policy committee will act only on recommendations by the chairman of a technical committee or an ad hoc committee or referee.

DOCUMENTATION OF PROPOSALS AND RECOMMENDATIONS

Documentation must include: (1) description and laboratory data pertinent to the issue at hand, (2) an estimate of the importance and geographic extent of any proposed new taxon, (3) an evaluation of the impact of the proposal on parts of Soil Taxonomy not directly addressed by the proposal and (4) an assessment of the significance of the proposal for the objectives of the Soil Taxonomy.

DISTRIBUTION OF APPROVED AMENDMENTS

Approved amendments will be published in the Soil Taxonomy Handbook, Soil Taxonomy News, and the Soil Science Society of America Journal.

Amendments will also be incorporated in the computer record of the "Key to Soil Taxonomy" and included in the next printing of the "Key." It is expected that the "Key" can be reissued frequently.

SOIL TAXONOMY SUPPORT SYSTEMS

The orderly development of Soil Taxonomy requires the establishment of a system to maintain records on proposals, on pedon data, and on taxa that have been recognized explicitly (such as series descriptions) or implicitly such as the legends of soil maps or other technical documents. These support systems have been established in the United States and in some other countries. Some of them are computerized.

Equivalent formal and orderly systems on a worldwide basis must be established. Such systems should be computerized to the greatest possible extent.

RESOLUTIONS AND RECOMMENDATIONS

The following resolutions and recommendations were submitted, discussed, and approved during the Closing Session of the Workshop on 11 November 1982.

1. The participants of the workshop highly commend the sponsoring organizations, particularly the Soil Survey Administration of the Sudan, for their efforts in planning, organizing, and conducting the conference and field excursions.

Proposed by W. M. Johnson
Seconded by R. Tavernier
Motion carried unanimously

2. The workshop participants recommend that International Soil Classification Committees investigate the use of models to simulate definitions of taxa as a means of improving Soil Taxonomy. Computer models that use diagnostic criteria as input data may be used to evaluate proposed revisions.

Proposed by I. Szabolcs
Seconded by R. S. Murthy
Motion carried unanimously

3. The participants recommend that ICOMERT make an effort to standardize procedures for sampling Vertisols and distribute these procedures to all cooperators.

Proposed by R. S. Murthy
Seconded by L. P. Wilding
Motion carried unanimously

4. The workshop participants recommend that the International Society of Soil Science be requested to prescribe standard horizon designations for Vertisols. The need for a special subordinate horizon distinction is recognized.

Proposed by W. D. Nettleton
Amended by W. G. Sombroek; seconded by R. S. Murthy
Motion carried unanimously

5. The workshop participants recommend that stronger efforts be made to improve soil moisture and temperature regime definitions. Moisture regimes of soils of the tropics, especially Vertisols, need particular study.

Proposed by G. A. Razig
Amended by K. W. Flach; seconded by A. Van Wambeke
Motion carried unanimously

6. The participants acknowledge the excellent soil survey progress made by the Soil Survey Administration of the Sudan. Realizing that Torrerts and related soils are perhaps more extensive in The Sudan than most other countries and realizing the needs of ICOMERT to obtain more data on these soils from The Sudan, it is recommended that the Soil Survey Administration be assisted in soil research and classification activities in order to expedite the work of ICOMERT.

Proposed by R. Tavernier
Seconded by H. Neel
Motion carried unanimously

7. The participants recommend that organizers of future workshops consider identifying at least one benchmark soil on an experimental station. The site should have long-term climatic data and soil data that are suitable for entry in an international data base.

Proposed by G. Uehara
Amended by K. W. Flach; seconded by W. G. Sombroek
Motion carried unanimously

8. The participants recommend that laboratory data and profile descriptions of the host country should be included in workshop materials for comparison with official descriptions and data of profiles selected for the excursions.

Proposed by H. Fadul
Seconded by W. G. Sombroek
Motion carried unanimously

9. The participants recommend that the control section for particle size and mineralogy and the spacing of cracks in Vertisols be studied for possible improvement in the definition of Vertisols. These items could be discussed by ICOMERT correspondents.

Proposed by A. K. El-Obeid
Seconded by W. D. Nettleton
Motion carried unanimously

10. The participants acknowledge the value of the LABEX program and recommend that it be continued and expanded to include data from additional countries.

Proposed by R. Tavernier
Seconded by R. Herbillon
Motion carried unanimously

11. Recognizing the excellent quality of visual aids used in some presentations at this workshop, the participants request that the organizing committee of future workshops encourage speakers to produce high quality visuals.

Proposed by L. P. Wilding
Seconded by K. W. Flach
Motion carried unanimously

12. The participants recommend that cooperators send typical pedon descriptions and data for proposed taxa to ICOM chairmen. The work of ICOMs is much more effective and objective if such descriptions and data are available for evaluation.

Proposed by J. Comerma
Seconded by R. Tavernier
Motion carried unanimously

APPENDIX

PROGRAM

MONDAY, 1 November 1982

Participants arrive in Khartoum
Registration, Grand Hotel

TUESDAY, 2 November 1982

0800 Registration of Sudanese participants, Friendship Hall Conference Centre (FHCC)

OPENING CEREMONY
Chairman: H.H. Abdulla, Director, Soil Survey Administration
Venue: Regional Hall, FHCC

0900 Introductory Statements

Dr. K.W. Flach, Associate Deputy Chief for Natural Resource Assessments, Soil Conservation Service, U.S. Department of Agriculture

Dr. M. El-Kash, Director General, Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD)

H.E. The Ambassador of the United States, C. William Kontos

0945 Opening of the Workshop - H.E. The Minister of Agriculture and Irrigation

1000 Refreshments

TECHNICAL SESSION I: PERSPECTIVES
Chairman: L.P. Wilding
Venue: Regional Hall, FHCC

1100 Keynote Address
L.D. Swindale: Constraints to agricultural development in the arid and semiarid regions of the world

1145 W.M. Johnson: Soil classification and soil survey for agricultural development

1215 A. Osman: Combatting desertification in the Arab world

1245 M. O. Saleh: Agriculture in the Sudan - History and prospects

1315 Discussion

1330 Lunch

TUESDAY, 2 November 1982 (cont'd)

TECHNICAL SESSION II: CLASSIFICATION OF ARIDISOLS
Chairman: A.R. Van Wambeke
Venue: Local Hall, FHCC

1530 A. Osman, ICOMID

1630 Refreshments

TECHNICAL SESSION III: FIELD TRIP BACKGROUND
Chairman: H. Ghanem
Venue: Local Hall, FHCC

1700 H.H. Abdulla: The physiography of central Sudan

1730 I.A. Babikir: Land use in the clay plain of the Sudan

1800 M.A. Ali: Soils of the Sudan

1830 Discussion

1900 Adjourn

1930 RECEPTION, Omar Khayyam Terrace, Grand Hotel

Night in Khartoum

WEDNESDAY, 3 November 1982

FIELD TRIP 1: NORTH-EASTERN VICINITY OF KHARTOUM (80 km)

0730 Dep. Grand Hotel
0830 Arr. Pedon S1
Discussion leader: J. A. Comerma
1030 Dep. Pedon S1
1045 Arr. Pedon S2
Discussion leader: H. Ikawa
1215 Dep. Pedon S2
1245 Arr. Grand Hotel

Lunch

TECHNICAL SESSION IV: SOIL CLIMATIC REGIMES
Chairman: I. Szabolcs
Venue: Local Hall, FHCC

1530 A.R. Van Wambeke: ICOMMORT

1630 R. Tavernier: Calculated soil moisture and temperature regimes in the Sudan and adjacent areas

WEDNESDAY, 3 November 1982 (cont'd)

1650 Refreshments

1720 R. Stuart, J. King and A.R. Van Wambeke: Soil moisture regime calculations for the Yemen Arab Republic

1740 W.G. Sombroek and J. Scholten: A proposal for refinement of the use of soil moisture regimes at high categoric levels of Soil Taxonomy

1800 R.L. Guthrie: Refinement of taxa based on soil moisture regimes

1820 Discussion

1900 Adjourn

Night in Khartoum

THURSDAY, 4 November 1982

FIELD TRIP II: KHARTOUM - WAD MEDANI (190 km)

0800 Dep. Grand Hotel
0930 Arr. Pedon S3
Discussion leader: A. Souissi
1130 Dep. Pedon S3
1330 Arr. Wad Medani, hotel check-in

Lunch at assigned hotels

'CURSION TO THE GEZIRA SCHEME

1500 Dep. Wad Medani
1515 Visit Gezira Research Station
1600 Tour of the Gezira Scheme
1800 Visit Headquarters of Gezira Scheme
1900 Dinner at Barakat
2030 Return to Wad Medani

Night in Wad Medani

FRIDAY, 5 November 1982

FIELD TRIP III: GEZIRA (30 km)

0800 Dep. Wad Medani
0830 Arr. Pedon S4
Discussion leader: H. Neel

FRIDAY, 5 November 1982 (cont'd)

1000 Dep. Pedon S4
1015 Arr. Pedon S5
Discussion leader: W.G. Sombroek
1215 Dep. Pedon S5
1230 Arr. Wad Medani

Lunch at assigned hotels

1430 Dep. Wad Medani for Gezira Research Station

TECHNICAL SESSION V: VERTISOLS
Chairman: S. Abdul Ghani
Venue: Conference Room, Gezira Research Station

1500 J. A. Comerma: ICOMERT

1600 Refreshments

1630 L. P. Wilding: Genesis of Vertisols

1650 G. Uehara: Application of geostatistics to the spatial variability of Vertisols in the Sudan

1710 W. D. Nettleton, R. B. Grossman, B. R. Brasher, and T. D. Cook: Application of pedology to plant response predictions for tropical Vertisols

1730 O. A. Fadl: Soil-water relationships in Vertisols

1750 Discussion

1830 Adjourn, return to Wad Medani

1900 Dinner at the Gezira Club

Night in Wad Medani

SATURDAY, 6 November 1982

FIELD TRIP IV: WAD MEDANI - ABU NAAMA - WAD MEDANI (500 km)

0700 Dep. Wad Medani
1030 Arr. Kenaana Research Station, Abu Naama
Pedon S6
Discussion leader: W. Luzio
1230 Dep. Pedon S6

Lunch at Kenaana Research Station

SATURDAY, 6 November 1982

1400 Dep. Kenaana Research Station
1630 Arr. Pedon S7
Discussion leader: P. Vijarnsorn
1730 Dep. Pedon S7
1745 Refreshments at Sennar Sugar Factory
1815 Dep. Sennar Sugar Factory
1930 Arr. Wad Medani

Night in Wad Medani

SUNDAY, 7 November 1982

FIELD TRIP V: WAD MEDANI - GEZIRA - KHARTOUM (250 km)

0700 Dep. Wad Medani
0745 Arr. Pedon S8
Discussion leader: R.L. Guthrie
0945 Dep. Pedon S8
1300 Arr. Khartoum

Lunch

1800 Optional trip to Omdurman Market

Night in Khartoum

MONDAY, 8 November 1982

FIELD TRIP VI: VICINITY OF KHARTOUM (65 km)

0800 Dep. Grand Hotel
0830 Arr. Pedon S9
Discussion leader: H. Dawoud
1015 Dep. Pedon S9
1115 Arr. Pedon S10
Discussion leader: H. Ghanem
1210 Arr. Grand Hotel

Lunch

TECHNICAL SESSION VI: VERTISOLS OF AUSTRALIA, AFRICA AND ASIA
Chairman: D.T. Pendleton
Venue: Local Hall, FHCC

1500 J.W. McGarity: Vertisols of Australia

MONDAY, 8 November 1982 (cont'd)

1520 M. F. Purnell: Relationships between Vertisols and lengths of growing period in the developing countries

1540 P. Vijarnsorn: Vertisols of Thailand

1600 Discussion

1630 Refreshments

1700 R. S. Murthy: Vertisols and associated soils of India - Distribution, morphology, chemistry and taxonomy

1720 A.A. Dayot: Vertisols of the Philippines

1740 W. G. Sombroek and H. Van Baren: The Vertisols of the ISM monolith collection

1800 Discussion

1830 Adjourn

Night in Khartoum

TUESDAY, 9 November 1982

TECHNICAL SESSION VII: VERTISOLS OF THE AMERICAS
Chairman: R. Tavernier

0830 R. L. Guthrie and J. D. Nichols: Distribution and classification of the Vertisols of the United States, Puerto Rico and the U.S. Virgin Islands

0850 H. Ikawa: Vertisols of Hawaii

0910 N. Ahmad: Acid Vertisols of the tropics

0930 Discussion

1000 Refreshments

1030 J. A. Comerma: Vertisols of Venezuela

1050 W. Luzio: Vertisols of Chile

1110 M.C.A. Razig: Genesis and classification of some soils of Western Sudan

1130 Discussion

TUESDAY, 9 November 1982 (cont'd)

1200 Adjourn

Lunch

TECHNICAL SESSION VIII: SPECIAL PROPERTIES OF ARIDISOLS AND VERTISOLS

Chairman: J. W. McGarity

Venue: Local Hall, FHCC

1500 B. F. Hajek: Mineralogy of Aridisols and Vertisols

1530 K. W. Flach, W. D. Nettleton and J. D. Nichols: Evaluation of the mollic subgroups of Aridisols

1600 J. E. Witty: Calic and gypsic horizons

1620 I. Szabolcs: Assessment of soil salinity and alkalinity

1640 Discussion

1700 Refreshments

1730 W. A. Blokhuis: Relationships between morphological properties and drainage in Vertisols

1750 E. Schlichting: The water/air regime in swelling/shrinking soils

1810 Discussion

1830 Adjourn

Night in Khartoum

WEDNESDAY, 10 November 1982

TECHNICAL SESSION IX: MANAGEMENT OF VERTISOLS

Chairman: M. O. Saleh

Venue: Local Hall, FHCC

0830 S. M. Virmani: Management of Vertisols for maximizing crop production

0900 A.S.P. Murthy: Management of Vertisols in India

0930 Discussion

1000 Refreshments

1030 M. A. Mahmoud: Management of Vertisols for rainfed crop production in the Sudan

WEDNESDAY, 10 November 1982 (cont'd)

1100 M. B. Said: Management of irrigated Vertisols in the Sudan

1130 H. M. Ishag: Potential yield of groundnuts in the Gezira environment

1200 Discussion

1230 Adjourn

Lunch

TECHNICAL SESSION X: MANAGEMENT OF ARIDISOLS
Chairman: A.S.P. Murthy
Venue: Local Hall, FHCC

1500 H. Lueken and F. Brueneberg: Management of Aridisols - A general appraisal

1530 M. O. El Karouri: Management of Aridisols in the Sudan

1600 H. Hamdi: Management of Aridisols in Egypt

1620 D. T. Pendleton: Use of soil classification to predict composition and productivity of natural grazing lands

1640 Discussion

1710 Refreshments

TECHNICAL SESSION XI: ICOMID
Chairman: K. W. Flach
Venue: Local Hall, FHCC

1730 Discussion, leader: A. Osman

1830 Adjourn

Night in Khartoum

THURSDAY, 11 November 1982

TECHNICAL SESSION XII: ICOMERT
Chairman: R. S. Murthy
Venue: Local Hall, FHCC

0830 Discussion, leader: J. A. Comerma

1000 Refreshments

THURSDAY, 11 November 1982 (cont'd)

TECHNICAL SESSION XIII: INTERNATIONAL ACTIVITIES
Chairman: W. M. Johnson
Venue: Local Hall, FHCC

1030 F. H. Beinroth and G. Uehara: The International Benchmark Sites Network for Agrotechnology Transfer

1115 K. W. Flach: The Soil Management Support Services

1130 W. G. Sombroek: The LABEX program of ISM

1145 E. Schlichting: The international reference base for soil classification

1200 K. W. Flach: Procedures for amendments of Soil Taxonomy

1220 Discussion

1230 Adjourn

Lunch

TECHNICAL SESSION XIV: RECOMMENDATIONS OF THE WORKSHOP
Chairman: M. A. Ali
Venue: Local Hall, FHCC

1500 Consideration of commendations and recommendations
Discussion leader: F. H. Beinroth

1700 Refreshments

CLOSING SESSION
Chairman: H. H. Abdulla
Venue: Local Hall, FHCC

1730 The workshop in retrospect - L. P. Wilding

1745 The impact of the workshop in the Sudan - M. A. Ali

1800 Importance of the workshop to the soil map project of the Arab countries - A. Osman

1815 Vote of thanks - W. G. Sombroek

1830 Adjourn

2000 CLOSING DINNER, Omar Khayyam Terrace, Grand Hotel

FRIDAY, 12 November 1982

Participants depart Khartoum

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