NBSS Publ. 42 Research Bull.

LAND EVALUATION FOR LAND USE PLANNING

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J. Sehgal

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ICAR

ureau of Soil Survey & Land Use Planning

(NDIAN COUNCIL OF AGRICULTURAL RESEARCH)

NAGPUR-440 010

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(Papers of the Indo-UK Workshop)

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About the NBSS&LUP

The National Bureau of Soil Survey and Land Use Planning, Nagpur, is a premier Institute in the country under the administrative control of the Indian Council of Agricultural Research (ICAR).

The Bureau was set up in the year 1976 with the mandate of providing research input in the soil resource mapping, soil correlation and classification, soilscape relationships, agro-ecological zoning and land degradation for optimising land use in the country. The Bureau has been engaged in carrying out soil resource mapping, agro-ecological zoning and mapping of degraded soils at the country, state and district levels.

The research activities of the Bureau have resulted in identifying various applications of soil surveys and mapping in the light of timely requirements of the country with the ultimate objective of sustainable agricultural development. The present publication "Land Evaluation for Land Use Planning" is the proceedings of the Indo-UK Workshop held at NBSS&LUP, Headquarters, Nagpur and at its Regional Centre Bangalore in September 1990.

Citation: Dent, D.L. and Deshpande, S.B. (eds) (1993). Land Evaluation for Land Use Planning (papers of Indo-UK Workshop). NBSS Publ. 42, NBSS&LUP, Nagpur, India. 167p.

TO OBTAIN COPIES OF THIS PUBLICATION, PLEASE WRITE TO:

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ISBN : 81-85460-21-3

October, 1993

Printed at the Printing Press; National Bureau of Soil Survey and Land Use Planning, IARI Campus, New Delhi - 110 012.

FOREWORD

This workshop was the culmination of a programme of collaboration between the U.K. Natural Resources Institute and the National Bureau of Soil Survey and Land Use Planning (NBSS&LUP) in India. The programme included exchange of senior staff and extended training of younger scientists at several institutions in the U.K. The goal was to strengthen the training capability of NBSS&LUP, ultimately to offer training to international standards for scientists from the developing world in soils for development and land use planning.

The workshop provided the opportunity for trainees to share their newly-polished skills by presenting the results of their research. At the same time, some UK specialists were invited to chart possible ways forward.

The working papers, which include invited reviews by UK specialists, provide a snapshot of the state-of-the-art of soil survey and land use planning in India at an exciting time: a time when we are taking on board new ideas and developing new methods of our own. In this volume, the papers are arranged according to the technical sessions of the workshop - methods of land resources survey, land evaluation and farming systems research, and computer-based information systems. The conclusions of working groups on each theme are also appended.

It is my pleasant duty to thank Mr. V.J. Nesargi and his staff at the British Council, Bombay, who facilitated the entire programme. The universities of East Anglia, Reading and Sheffield, the Cranfield Institute of Technology and the Ordnance Survey; many members of staff of NBSS&LUP Staff who worked for the success of the workshop, beside those who presented their papers; and Miss L.S. Morgan, Mrs. J.E. Parsons and Miss Rohini Mendhekar for wordprocessing.

Finally, my thanks to the editors for their labour of love.

(J. Sehgal)
Director,
NBSS&LUP

ACKNOWLEDGEMENTS

The Indo-UK Workshop was held from 24 to 30 September 1990 at Nagpur and Bangalore. The success of the Workshop was possible due to the sincere efforts of the staff of the NBSS&LUP, especially at Nagpur and Bangalore, the chairpersons and rapporteurs of technical sessions, and the presence of dignitories from India and U.K., to whom we convey our heartiest thanks.

- Dr. N.S. Randhawa former Director General (ICAR) for inaugurating the Workshop, and Dr. I.P. Abrol, DDG (SA&AF) for presiding over the function.

- Dr. O. Challa, Dr. R.K. Saxena, Dr. A.R. Kalbande, Mr. R.M. Pofali, Dr. D.K. Pal, Dr. K.S. Gajbhiye, Mr. Y.M. Patil, Mr. S.R. Nigote, Dr. J. Prasad, Mr. C.S. Harindranath, Mr. P.S.A. Reddy, Mr. S.R. Nagabhushana, Mr. Sohan Lal, amd Mr. B.P. Rajora for shouldering responsibilities for different activities, and also the members of their teams for their help, in connection with the Workshop.

- Last but not the least all other staff members of the NBSS&LUP for their help in many ways to make the Workshop a success.

Workshop Organisers:	**S.T. Gaikawad** **L.R. Hirekerur** **J. Sehgal**	
Workshop Field Trips Organisers:	**K.S. Bhaskar** **R.K. Batta** **S.C. Yadav** **W.V. Bankar** **S.T. Gaikawad**	**(Nagpur)**
	S.R. Nagabhushana **K.R. Venugopal** **P. Krishnan** **A. Natarajan**	**(Bangalore)**

CONTENTS

LAND USE PLANNING BASED ON SOILS AND AGRO-ECOLOGICAL ZONES

J Sehgal, O Challa, J P Sharma and P H Balbudhe

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INTRODUCTION

With the population of India increasing at an annual rate of 2.1 per cent, the land available per head has been declining dramatically from 0.5 ha during 1960s to an anticipated 0.15 ha by the turn of the century. With the increasing pressure on the land, deforestation has been increasing to about 1 m ha per year and another 1 m ha is being degraded by other processes every year. About half of the country is now suffering from some kind and degree of soil degradation.

It is essential to develop strategies to arrest further degradation and assist in optimising land use, which will ensure both economic prosperity and ecological security. In his presidential address to the 12th Congress of the Internaltional Society Soil Science, held at New Delhi, Kanwer (1982) appealed "Save the soil and save humanity". The establishment of National Land Resource Conservation and Development Commissions and of Land Use Boards at the Central and State levels is statement of political will and administrative support for this effort by the Government of India.

Since soils are our most valuable, life-supporting natural resource, knowledge about the potential and problems of different soils, their extent and distribution is essential for developing rational land use. This knowledge can be obtained only through soil resource mapping using sound criteria (Sehgal 1990). Many countries have soil survey organisations whose basic responsibility has been to map soil resources as a base for designing irrigation, combatting soil degradation, planning land use, etc. Many such organisations have been working for several decades. They have produced a huge database as maps and reports, but in the raw form that could not be taken into account in development plans and, where specific information is sought, the data are difficult to interpret. This has been ascribed to poor presentation of results; lack of communication among soil scientists, agriculturists and economists; insufficient interpretation on the part of soil surveyors; or lack of interest by the planners (Dudal 1979).

For choices between alternative land uses, information is needed in terms of soil properties rather than soil taxa, so soil properties have to be given priority in the soil legend. Besides, land systems that include elements of landforms, water regime and vegetation, may provide a better index of regional land potential than maps based on a soil profile properties alone (Somebroek and Van de Weg 1983). For this purpose, the use of satellite imagery to help in distinguishing landforms and vegetation, considered along with the soil properties, is a sound base for mapping and making land use recommendations (Sehgal et al. 1989).

Two initiatives are pre-requisites for national land use planning. One is soil resource mapping, at 1:250 000 for regional planning and at 1:5 000 for microcatchment planning. The other initiative is agroecological zoning to identify different kinds of broad areas that have the capability of diversification (Planning Commission 1989).

CASE STUDIES

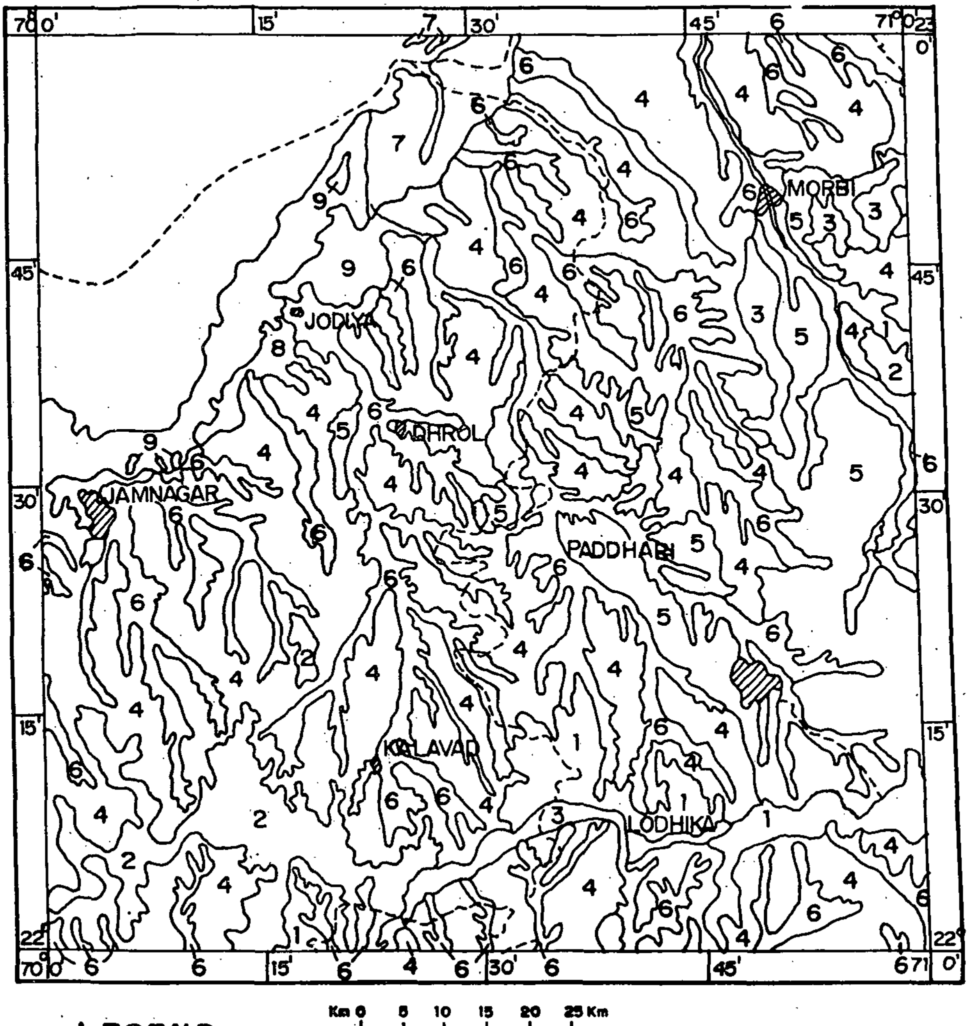
In order to plan land use at regional and catchment levels, Rajkot region in Gujarat and Khapri microcatchment in Nagpur district were selected. Rakjot is a semi-arid area characterised by hot summers and mild winters with mean annual temperature of 25.9 to 26.7°C and a mean annual rainfall of 580 to 670 mm. Basalt is the main geological formation in the area. The Khapri catchment is located at latitude 21°8'N and longitude 78°32'E, 58 km from Nagpur on the Calcutta-Bombay highway. It covers an area of 122 ha, also built of basaltic lava flows. The climate is subtropical subhumid with a mean annual rainfall of 1127 mm and mean annual temperature of 28.9°C.

Methods: A 3-tier approach was used comprising image interpretation, field survey (including soil sample analysis), and cartography (Sehgal et al. 1989). This provides greater efficiency than conventional methods at the reconnaissance level of mapping.

1:250 000 Landsat false-colour composites produced by a combination of bands 1, 2 and 4 were used for visual interpretation of regional physiography, as expressed by the integrated effects of geology, terrain and environmental conditions. Further sub-divisions were made on the basis of landscape elements together with tone and texture, singly or in combination.

Field survey was undertaken to identify and correlate soils with physiography. This included intensive survey of sample strips (7 or 8 on each sheet) cutting across most of the photomorphic units, at-random checking to confirm and finalise the above relationship (if existing) and, also, regular 10 km grid observations. The soil map produced in the field showed associations of soil families with phases such as surface texture, salinity, stoniness, erosion and waterlogging. The field map was transferred to 1:250 000 scale topographic sheets using an optical reflecting projector. Soil samples representing benchmark soils and systematic grid samples were analysed for various properties as given in the Field Manual (Sehgal et al. 1987).

Figure 1 illustrates the final state soil map at the level of associations of soil families with phases and pedological classification according to Soil Taxonomy (Soil Survey Staff 1975). Figure 2 shows the soils of the microcatchment, mapped as soil series and phases of series.



LEGEND

1	Moderately shallow to shallow, moderately well drained clayey soils, slightly eroded	Vertic Ustochrept, Lithic Ustorthent
2	Shallow, well drained clayey soils, severely eroded	Rock outcrop, Lithic Ustorthent
3	Very shallow, well drained clayey soils, severely eroded	Lithic Ustorthent, Lithic Ustochrept
4	Moderately deep, well drained clayey soils, slightly eroded	Typic Chromustert, Vertic Ustochrept
5	Shallow to moderately deep, well drained clayey soils, moderately eroded	Lithic Ustochrept, Vertic Ustochrept
6	Moderately shallow, moderately well drained clayey soils, slightly eroded	Vertic Ustochrept, Typic Chromustert
7	Deep, poorly drained clayey soils, very severe salinity	Typic Halaquept
8	Moderately deep, poorly drained clayey soils, severe salinity, strong sodicity	Typic Chromustert, Vertic Ustochrept
9	Salt pan	—

REFERENCE

- District boundary
- River or Stream, Tank
- Location
- Soil units

Figure 1. Soil map of Rajkot area, Gujarat

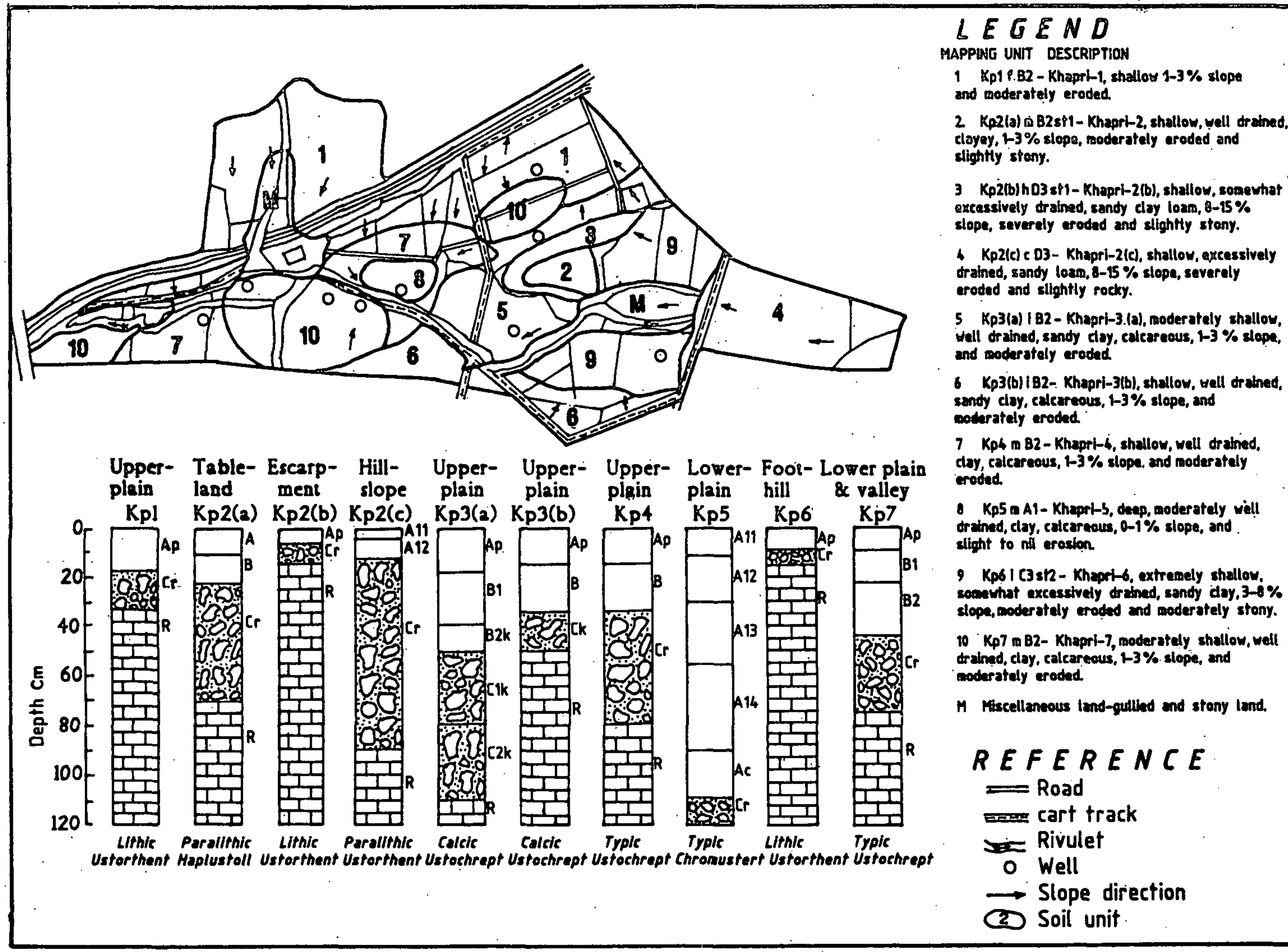


Figure 2. Map of Khapri catchment, Nagpur

For agroecological zoning, information on physiography, soils, rainfall, temperature, potential evapotranspiration and length of the growing period was used (Higgins et al 1982). These variables were mapped in terms of soil landscape, climate and length of moisture availability period. By generalization and by superimposing these three maps, a map of agroecological regions was generated (Sehgal et al. 1990). Figure 3 shows the more refined agroecological subregion map (Sehgal et al 1992) used for the present investigation. The case study areas fall in the agroecological subregions 5.1 and 10.2, profiles of which are given in Figs 4a and 4b.

The agroecological subregions map superimposed on the soil resource map on 1:250 000 scale resulted in agro-ecological mapping units that provide details of the soils, landform and climatic conditions needed for land evaluation and land use planning at regional level.

LAND EVALUATION

Land evaluation integrates data supplied by soil survey with other important components, such as climate and land use, that determine land qualities. According to Dudal (1987), special attention needs to be given to the climatic parameters which determine the upper limits of crop production.

For land use planning, we must also assess the needs of the farming community and find ways to realise them. We must feel the pulse of the farming community and involve them in the process, because they are the actual land users; and involve politicians because political will is needed to push things through; and involve technical people who will see the technical feasibility of the plan and its ecological sustainability.

Soil-site Suitability Evaluation

The soil-site suitability for pearl millet, cotton, sorghum and groundnut (under rainfed conditions) has been assessed by matching the land characteristics of each mapping unit with the crop requirements at different limitation levels (Balbudhe 1990). The number and degree of limitations suggested the suitability class of each soil unit for a particular crop (Table 1). By comparing the suitability score of each mapping unit for different crops, the optimum use potential of the land was determined (Table 2).

i) Regional-Level Planning

Rajkot belongs to agro-ecological subregion 5.1 (hot, semi-arid with shallow and medium black clay soils, deep soils as inclusion). The characteristics of the agroecological units were evaluated for existing crops using the methodology developed by Sys (1985). The suggested criteria were modified according to experimental yield data of different crops obtained on soils having variable depth, texture, slope and drainage. The final suitability classes were validated by the actual yield data on comparable soils.

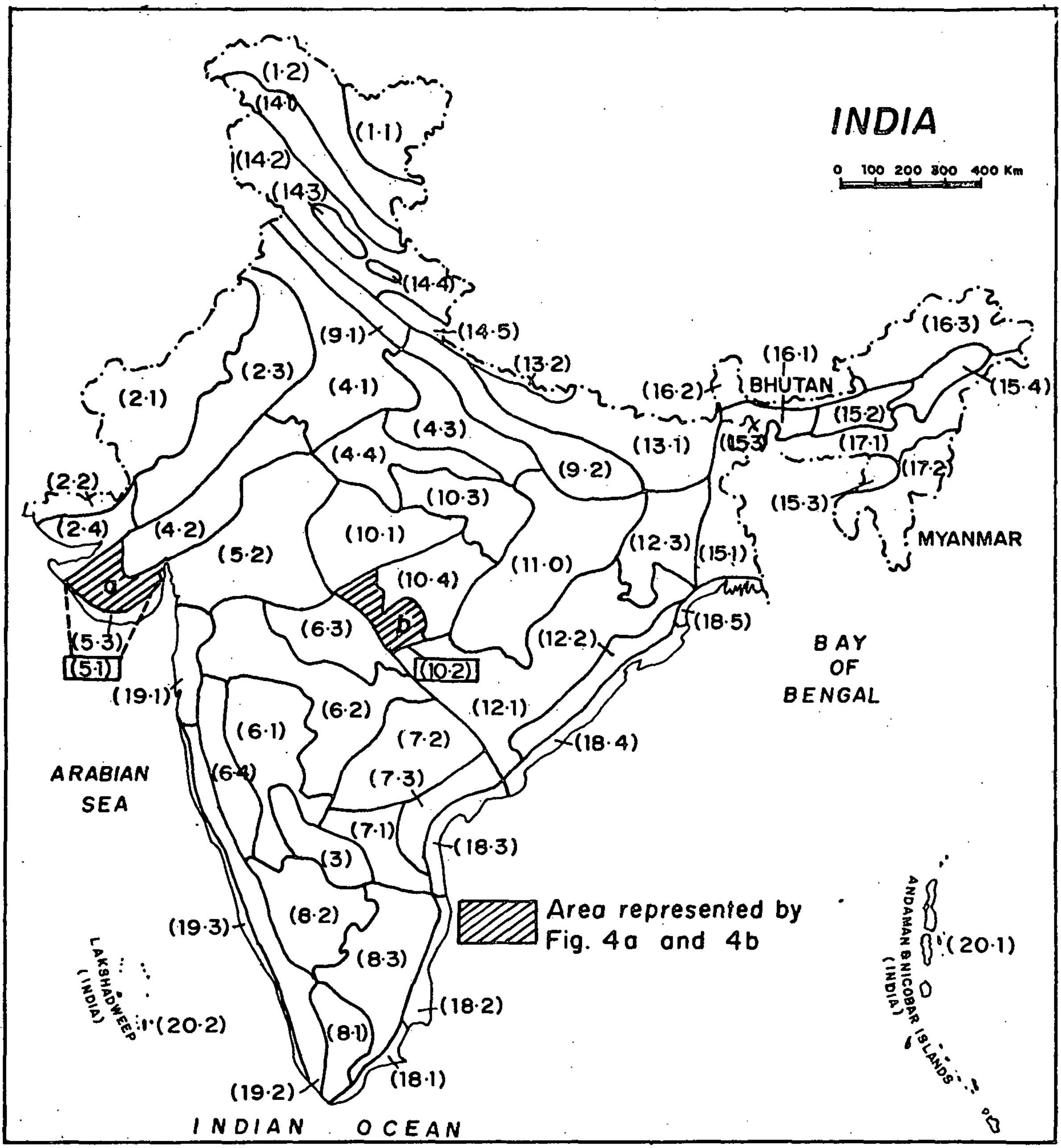


Figure 3. Agro-ecological subregions

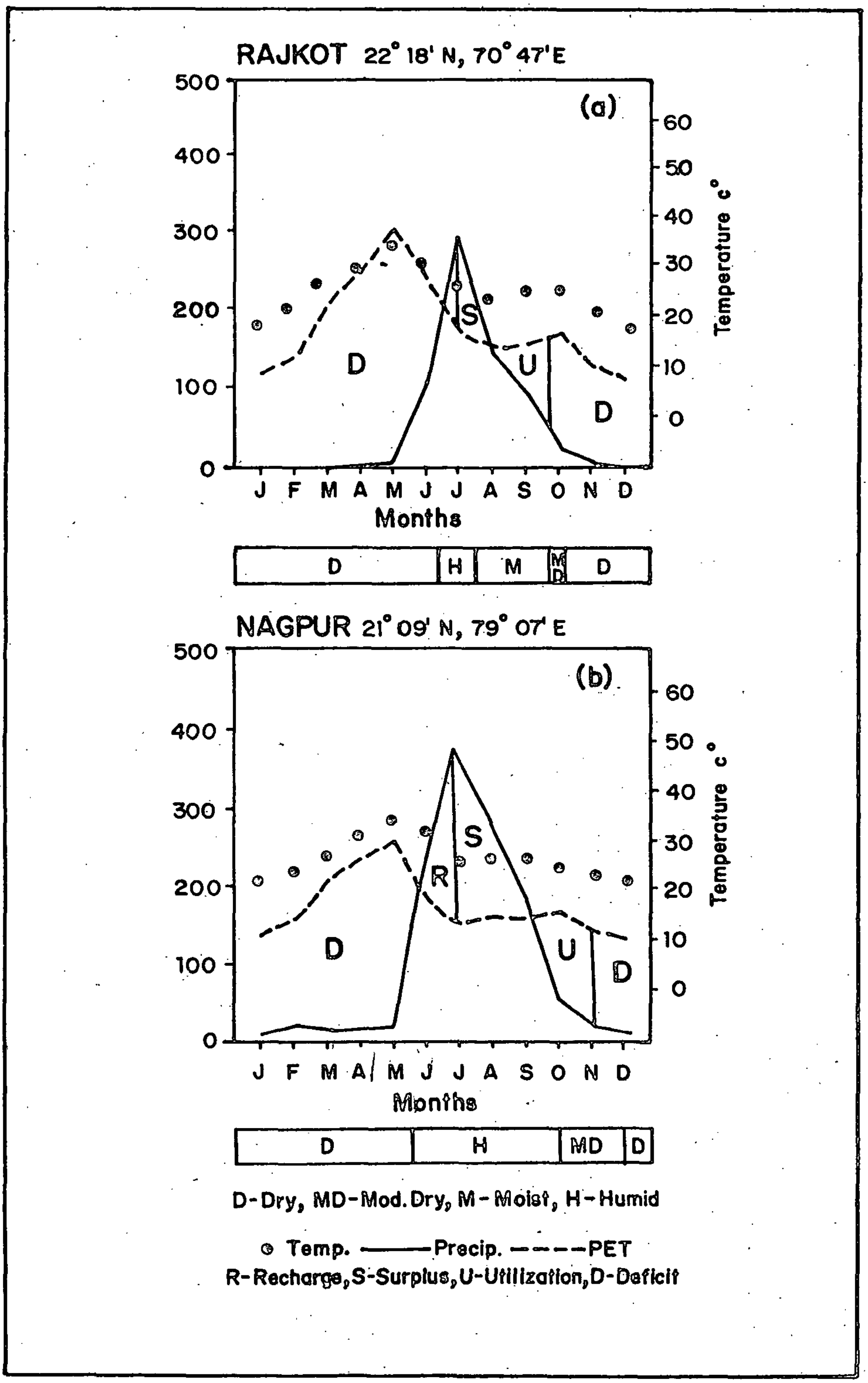


Figure 4. Water balances: (a) Rajkot, (b) Nagpur.

Table 1 Soil-site Suitability (present and potential) for different crops

Soil Unit	Suitability for:											
	Cotton		Groundnut		Sorghum		Pearlmillet		Pigeonpea		Soybean	
	(A)	(P)	(A)	(P)	(A)	(P)	(A)	(P)	(A)	(P)	(A)	(P)
					Rajkot							
I25I30/Cae2	N1	S3	S3	S2	S2	S2	S2	S2	-	-	-	-
I29K36/Cbe1	N1	S2	S2	S2	S2	S1	S2	S1	-	-	-	-
K28I26/Ece3	N2	S3	N2	N2	N2	N2	N2	N2	-	-	-	-
V1 I29/Cbe1	S3	S1	S2	S1	S2	S1	S2	S1	-	-	-	-
					Khapri							
Kp-1	N2	N2	N1	S3	S3	S3	-	-	N2	N2	N1	S3
Kp-2(b)	N2	N2	N2	N2	N2	N2	-	-	N2	N2	N2	N2
Kp-3(a)	S2	S2	S2	S2	S2	S2	-	-	S2	S2	S2	S2
Kp-4	S2	S2	S2	S2	S2	S2	-	-	S2	S2	S2	S2
Kp-5	S2	S1	S2	S2	S1	S1	-	-	S2	S1	S2	S2
Kp-6	N2	N2	N2	N2	N2	N2	-	-	N2	N2	N2	N2
Kp-7	S2	S2	S2	S2	S2	S2	-	-	S2	S2	S2	S2

A=Actual or present suitability class; P=Potential suitability class

SUITABILITY CRITERIA:

S1-Limitation of 1 (upto 3); S2-Limitation of 1 (more than 3) and /or of 2 (upto 3 correctable or upto 1 incorrectable); S3-Limitation of 2 (more than 3) and/or of 3 (upto 3 correctable or upto 1 incorrectable); N1-Limitation of 3 (more than 3) and/or 4 (upto 3 correctable or incorrectable)

Table 2 Existing and suggested cropping pattern for various agro-ecological units

Agro-ecological Unit	Existing cropping pattern	Suggested cropping pattern	Management practices
		Rajkot	
K28I26/Ece3:Semiarid hot; GP: 95 days	Cropping pattern common for all types of soils includes groundnut, cotton, sorghum, pearl-millet, pigeonpea, etc.	Pasture development and agro-forestry	Intensive soil conservation measures plantation on the sides of ridges
I29K36/Cbel:Semiarid hot; GP: 110 days		Groundnut, pigeonpea sorghum, pearlmillet	Field bunding, conservation of moisture
I25I30/Cce-2: Semiarid hot; GP: 100 days		Groundnut, pearmillet, sorghum (fodder) kharif pulses, castor	Strip cropping, graded bunding, growing short duration crops
V1 I29/Cbe-1: Semiarid hot; GP: 115 days		Cotton, sorghum, pearlmillet and *groundnut*	Field bunding, improved package of practices
		Khapri	
Kp-1(a): Dry subhumid hot; GP: 155 days	Cropping pattern common for all types of soils includes cotton, sorghum, groundnut, pigeonpea, gram, wheat, etc.	Pasture and forestry	Protective grazing
Kp-2(b): Dry subhumid hot; GP: 150 days		Forestry	Use of trench and ridge system of plantation
Kp-3(a): Dry subhumid hot; GP: 165 days		Groundnut, soybean, sorghum and pulses	Erosion control and field bunding
Kp-4: Dry subhumid hot; GP: 155 days		Groundnut, soybean, sorghum and pulses	Erosion control and field bunding
Kp-5: Dry subhumid hot; GP: 170 days		Cotton, sorghum, pulses, groundnut, and soybean	Soil and water conservation and adoption of improved package of practices
Kp-6: Dry subhumid hot; GP: 150 days		Forestry	Contour bunding
Kp-7: Dry subhumid hot; GP: 165 days		Soybean, sorghum, groundnut and pulses	Soil and water conservation measures

Table 1 indicates that soils in unit K28126 are totally unsuitable for farming because of their limitations of depth and erosion. These soils can, however, be used for pasture and forestry. Other soils are arable but their suitability varies for different crops. In many cases, potential land suitability can be raised by proper management.

Depending on the suitability classes of the agro-ecological units for different crops, a suggested land use has been proposed taking into consideration the present cropping pattern and the socio-economic conditions of the farmers (Table 2).

ii. Catchment-Level Planning

Like regional level planning, catchment planning involves survey of soil and water resources and assessment of land use and present productivity. The Khapri catchment represents agro-ecological region 10, that is, the hot subhumid with Red and Black soils, and subregion 10.2 that is hot dry-subhumid with shallow and medium Black soils (deep soils as inclusion) (Figs 3 and 4b).

The uplands carry shallow, sandy clay loams to clay loams underlain by weathered basalt. The plains and valleys have moderately deep to deep, clay loam to clayey soils. Out of the total area of 122 ha, the net sown area is 80 ha with most of the remainder under forest and pasture and 2 per cent under orchards.

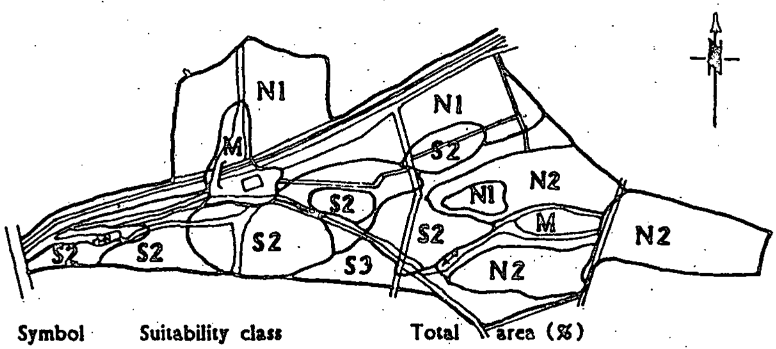
The soil mapping units were evaluated for cotton, sorghum, groundnut, soybean and pigeonpea (Table 1) and wheat. Based on the suitability of soils, suitability maps for different crops have been prepared (Fig 5) which show that units Kp-1, Kp-2(b) and Kp-6 are unsuitable for cropping but may be reserved for forestry and/or pasture. Kp-5 has high potential for cropping. Units Kp-7, Kp-4 and Kp-3(a) are moderately suitable for the major agricultural crops grown in the area but their suitability cannot be improved because of the limitations of texture and drainage. The above soil-site suitability for different crops has been validated with the actual yields obtained (Table 3).

APPLICATION OF SOIL SURVEY AND MAPS FOR LAND USE PLANNING

The application of soil survey depends on the quality of soil maps which is often evaluated by the purity of mapping units and the accuracy of map boundaries. To attain a high degree of accuracy, detailed mapping is required which can be very complex, expensive and time consuming. But the practical significance of the separations made depends on the level of generalisation at which the interpretations are desired.

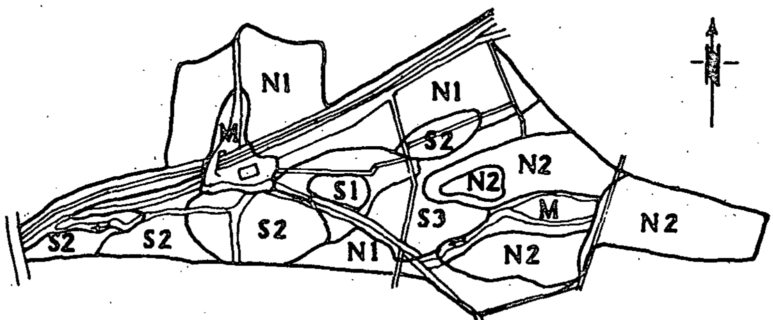
In low-intensity studies carried out at regional level, the factors influencing decision-making are climate, landform and soils. In this, the precision of boundaries between soil taxa may not be of primary importance. In more detailed studies, the usefulness of precise boundaries is limited to the smallest area that

Suitability for Groundnut / Soybean



Symbol	Suitability class	Total area (%)
S1	Very suitable	-
S2	Moderately suitable	37
S3	Marginally suitable	6
N1	Unsuitable (presently)	27
N2	Unsuitable (pres. & pot.)	30

Suitability for Wheat



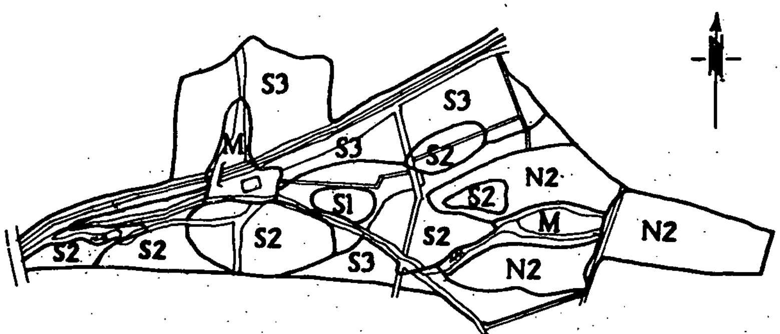
REFERENCE

- Road and Cart track
- Nala
- Boundary of watershed
- Soil boundary with symbol

Symbol	Total area (%)
S1	2
S2	15
S3	20
N1	32
N2	31

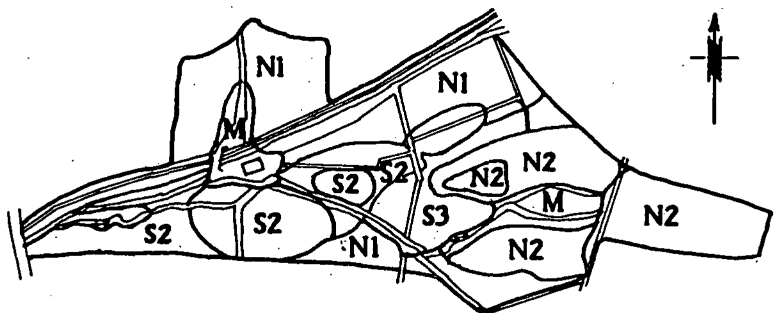
Figure 5a. Suitability for different crops

Suitability for Sorghum



Symbol	Suitability class	Total area (%)
S1	Very suitable	2
S2	Moderately suitable	34
S3	Marginally suitable	34
N	Unsuitable (presently)	-
N2	Unsuitable (pres. & pot.)	30

Suitability for Gram



REFERENCE

- Road and Carttrack
- Nala
- Boundary of watershed
- (S1) Soil boundary with symbol

Symbol	Total area (%)
S1	-
S2	27
S3	9
N1	32
N2	32

Figure 5b. Suitability for different crops

Table 3 Khapri catchment, actual (A) and potential (P) crop yield (Q/ha)* (Balbudhe 1990)

Soil mapping units	Cotton		Pigeonpea		Sorghum		Groundnut		Soybean		Wheat		Gram	
	A	P	A	P	A	P	A	P	A	P	A	P	A	P
Kp-1	3.7	5.2	6.1	6.3	15.0	22.6	5.0	7.0	6.6	9.0	7.5	10.5	3.5	5.6
Kp-3(a)	7.5	11.4	8.0	13.0	22.5	28.3	7.9	10.5	10.3	14.1	14.7	23.0	6.3	9.5
Kp-4	8.0	12.3	10.0	13.3	25.5	32.0	8.2	12.2	10.9	15.5	20.5	30.8	9.0	11.4
Kp-5	-	15.2	-	15.7	-	36.5	-	7.4	-	13.6	-	35.8	-	12.5
Kp-6	3.7	4.3	4.5	5.5	12.5	13.9	3.0	4.4	4.5	5.9	-	-	-	-
Kp-7	8.7	11.8	10.0	14.4	26.3	34.5	7.6	9.5	9.6	12.0	22.0	32.2	10.1	14.0

A=Actual yield data with farmers' management practices (low inputs)
P=Potential yield data with recommended level of management practices (experimental yield data)

can be managed separately (Dent and Young 1981). It is, therefore, seldom poslsible to develop a land use plan that takes full account of the soil variations occurring within short distances. Instead, land use planning has to be based on average conditions of manageable tracts of land, (not just for one crop but for a group of crops) with information on the input needed and the outputs that are expected. This study suggests that the delineation of agro-ecological units that provide complete information on the edaphic situation, used in conjunction with soil resource maps, provides a sound basis for optimizing land use.

For planning at the level of micro catchments, mapping at 1:250,000 may not be much use because of the limitations of scale. Here we need detailed soil maps that delineate soil series and their phases so as to develop optimum land use according to the suitability of the soils.

REFERENCES

Dent D.L. and A. Young 1981. *Soil survey and land evaluation.* Geo Allen and Unwin, London

Higgins G.M., A.H. Kassam, L. Naiken, G Fischer and M.M. Shah 1982. *Potential population supporting capacities of lands in the developing world.* Tech.Rept. IN7/73/523 FAO, Rome

Planning Commission 1989. *Agroclimatic regional planning, an overview.* Plannning Commission, Govt. of India, New Delhi

Sehgal, J.L. 1990. *Soil series criteria and norms.* Soil Series Bull.1, National Bureau of Soil Survey and Land Use Planning, Nagpur

Sehgal, J.L., D.K. Mahdel and S. Vadivelu 1990. *Agroecological regions of India.* National Bureau of Soil Survey and Land Use Planning, Nagpur

Sehgal, J.L., D.K. Mandal, C. Mandal and S. Vadivelu 1992. *Agro-ecological subregions of India.* Tech.Bull 35, National Bureau of

Soil Survey and Land Use Planning, Nagpur (in press)

Sehgal, J.L., R.K. Saxena and S. Vadivelu 1987. *Field Manual.* Tech.Bull 13, National Bureau of Soil Survey and Land Use Planning, Nagpur

Soil Survey Staff 1975. *Soil taxonomy: a basic system of soil classification for making and interpreting soil surveys.* Agriculture Handbook 436, U.S. Govt. Printing Office, Washington D.C.

Sombroek, W.G. and R.F. van de Weg 1983. Soil maps and their legends. Soil Survey and Land Evaluation 3,3, 80-87

Sys, C. 1985. Land evaluation. Algemeen Bestuur van de Ontwikkelingssamenwerking, Brussels

MAKING LAND INFORMATION MORE ACCESSIBLE

P. Bullock

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INTRODUCTION

Most countries of the world have a soil survey organisation whose responsibility it is to survey, monitor and research into soils. The remit of these organisations is generally to provide information about the soil resources that will form a basis for planning land use, conservation measures, combatting contamination and contribute to solutions of land-based problems generally.

Many of the soil survey organisations have been in being for several decades during which time they have amassed large amounts of valuable information. Although some of this has been published in the form of soil maps and reports, much of it lies in filing cabinets unpublished. In this latter form it is unlikely to contribute significantly to the solution of agricultural or environmental problems. Much money has been spent collecting the information but a cost-benefit analysis would rarely be positive. This state of affairs needs to be improved.

REASONS FOR THE PREVIOUS LACK OF USE OF SOIL INFORMATION

There are three principal reasons, involving both the source organisations and the potential user organisations.

1) The information is usually in a form acceptable to soil surveyors but often not to other soil scientists and rarely to people at the practical, delivery-end of soil science, eg. agronomists, socio-economists. Many soil survey organisations have consistently failed to recognise the needs of the potential user and have been too inward-looking.
2) Because much of the information is stored in unpublished form in filing cabinets, the facility for manipulating different datasets from different sources is limited.

3) Soils have many functions: as the medium for plant growth, recycling of major and minor elements, foundations for buildings, a source and sink for pollutants, water storage and water recharge, substrate for soil fauna and microflora, and a substrate for feeding birds and animals, amongst others. Yet there is a disappointing ignorance on the part of many users of land of the importance of soils and the ways in which a better knowledge of soils would benefit their activities.

A major gap thus exists between the producer of basic soil information, the soil survey organisations, and the potential user of soil information, the many organisations involved in land-based activities.

THE PRESSING NEEDS OF INDIA

There is an urgent need for the dissemination of soil information to potential users in India. As Dr Randhawa, former Director General of the Indian Council for Agricultural Research, noted in his opening address, "there are 836 million people in India, 600 million of whom are involved in agriculture. There are over 100 million land holdings with 124 million hectares under cultivation, a proportion of which are under non-sustainable production. Some 150 million hectares of land are affected by soil erosion and there are other problems such as over-exploitation of natural support systems to agriculture, loss of biological diversity and large areas with a variety of environmental problems, for example, salinization, pollution. The valuable scientific information about the soils of India, now being amassed, needs to reach the people responsible for addressing these problems."

CLOSING THE GAP BETWEEN DATABASES AND THE USER OF SOIL INFORMATION

There are several steps that can be taken to facilitate the dissemination of information.

Making map legends more informative

The emphasis in map legends should be to provide simple, useful information capable of being understood by all would-be users. Too often in the past, legends have been dominated by soil classification systems whose jargon is gobbledygook to all except professional soil scientists. There is an important place for soil classification as a framework for research and technology transfer but soil map legends need to be simple and informative.

Land suitability and other thematic maps

A soil map can be a complex document but is capable of interpretation and simplification for a wide range of practical uses.

There have been major developments in land classification in recent years. Conceptually, there has been a change from the supply of a single product - a soil map or land classification map - which the user interprets for his/her own needs, to a flexible system in which the users define their needs, a model is set up and the information base is interrogated to provide the best possible response.

Agricultural land evaluation has moved from the general classification approach to one which an area of land is evaluated specifically to determine whether it meets the requirement of identified crops.

Although, initially, emphasis was given to determining land suitability for specific crops, it is recognised that the same methods can be used to examine the suitability of land for different management techniques, hazards to crop production, non-agricultural land use, risks to the environment and hydrological processes.

These derivative maps will have a direct application for a range of land users. The maps are in a form that can be readily understood by the users. Examples of thematic maps relating to Indian conditions are given in Table 1.

Computerised information systems

To respond to questions relating to agriculture and the environment requires the capability to store, manipulate and retrieve large amounts of data quickly. Commonly there is a need for different forms of data, for example data in map form combined with data from point observations. In most cases there will also be a need to combine data from a number of sources, for example, soil, climatic and socio-economic. A well developed database should be capable of doing all this and, in addition, should have the flexibility to take in new information, eventually to be used to provide sounder advice and more refined models. Information systems should be regularly added to as new research, monitoring and modelling results become available (Figure 1).

Information systems are being developed in a number of countries and provide a vital key to bridging the gap between the scientist, the land user and the policy maker.

Discussions with users of soil information

It is important to bring potential users into discussions at an early stage. The user needs to appreciate the spatial nature of soils, the fact that different soil types may behave differently, the influence of different soil properties and the interaction of soils with the prevailing climate. Soil scientists, for their part, can learn about the users' needs and thus improve the form and content of the information that is being assembled.

Table 1. Examples of thematic maps in support of land use policy and planning, soil protection, disaster management and impact assessment

1. SINGLE PROPERTY MAPS

-Textural class
-Organic matter content
-Acidity (pH)
-Soil depth
-Stoniness
-Water regime
-Permeability
-Drainage
-Nutrient status

2. SOIL BEHAVIOUR MAPS

-Irrigation need
-Reclamation potential
-Workability
-Trafficability
-Rainfall acceptance potential
-Leaching potential

3. SUITABILITY OF LAND FOR CROPS

-Sorghum
-Sugarcane
-Wheat
-Cotton
-Rice
-Millet
-Soybean
-Grams
-Horticultural crops
-Energy crops
-Grass
-Fruits

4. SUITABILITY FOR FORESTRY

-General suitability for forestry
-Species diversity
-Teak
-Eucalyptus
-Acacia

5. RISK OF DEGRADATION

-Wind erosion
-Water erosion
-Salinity
-Groundwater vulnerability
-Potential effects of deforestation
-Flooding
-Pollution

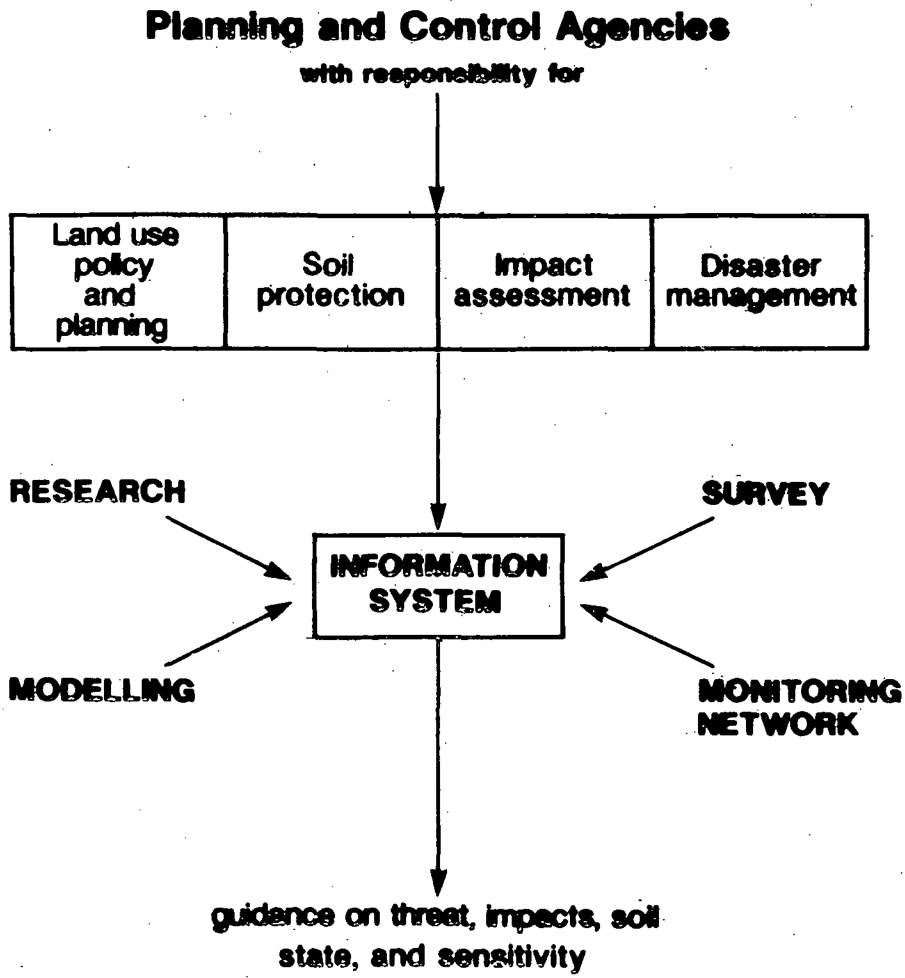

Figure 1. Information systems - the link between data collection and the policy-makers.

CONCLUSIONS

The National Bureau of Soil Survey and Land Use Planning is now in a strong position to make an impact on land users. It is approaching the conclusion of its 1:250 000 national soil mapping programme, with a number of states already complete. It now has a strong information base from which to interact with users. Implementation of some of the above recommendations is already underway. The development of a fully-fledged land information system would greatly facilitate the transfer of this valuable information.

WHAT DO WE MEAN BY LAND USE PLANNING?

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INTRODUCTION

At a critical point in the history of the English-speaking peoples, Winston Churchill begged the United States of America 'Give us the tools and we will finish the job'. It was 1941. He knew exactly what tools were needed because he had no doubt about the job.

We are not in that position. We have the tools. In this workshop, we are brandishing tools as diverse as colour printing, satellite imagery, soil survey, hydrological measurements, land evaluation and geographic information systems. But what is the job? What do we mean by land use planning?

Planning is the exercise of foresight to achieve certain goals. Before we start planning, then, we need to be certain of the goals. That is the first problem with land use planning; everyone has a direct interest in land use and their goals are not all the same. In India, there are 100 million farming families. At the other end of the spectrum there are government policy-makers who decree the legal basis of land tenure, water rights and land use and, to some extent, channel investment and manage the market for goods and services. In between, there is a wide range of agencies and special-interest groups that make decisions that affect land use. The goals of these different groups of decision-makers are often conflicting. Whose interests do we serve?

By land use planning, I mean making informed decisions about the use of land. There is one specific job to provide the information, the foresight, to support decision-making. There is another, different job to resolve the conflicts of interest between the disparate groups of people who have a hand in the use of the land and, also, the interest of the generations who will inherit it.

The mandate of the Bureau is to support decision-making. In this paper, I will explore the kinds of information needed to support decision-making in the context of a general procedure for land use planning.

TEN STEPS IN LAND USE PLANNING

Figure 1 depicts a sequence of steps in land use planning. Of course, each planning project is unique. But the steps are the same whether the purpose is to devise a farm plan or a national land use policy. The inputs and outputs indicated here refer to something in between, say a district land development project that includes a formal planning document.

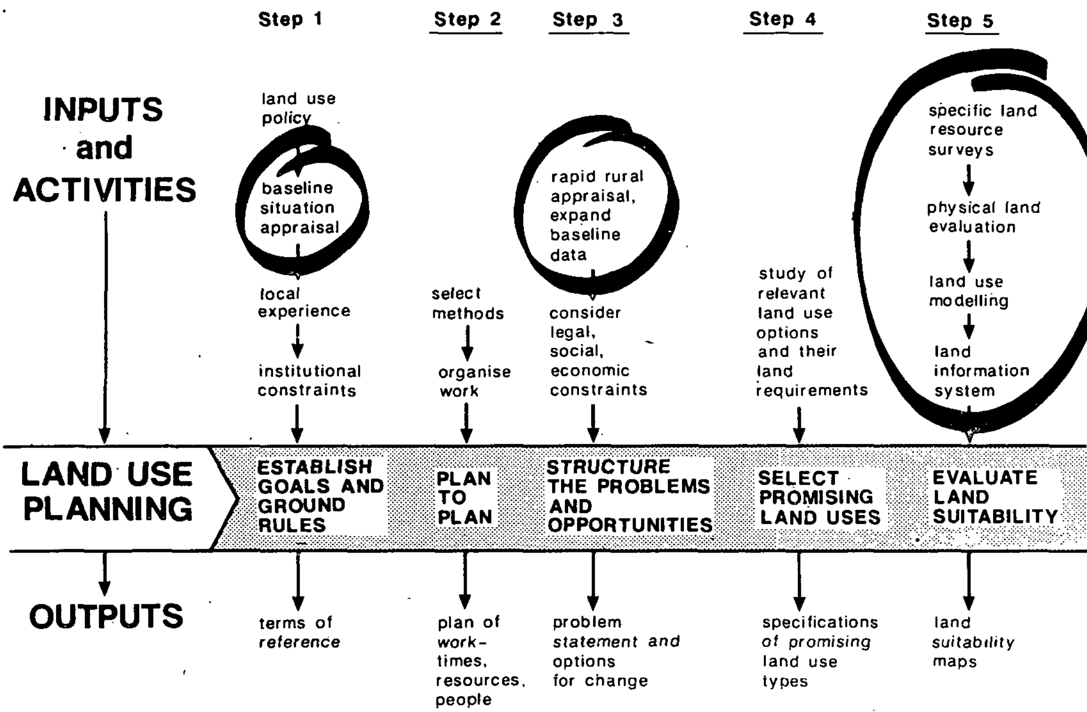
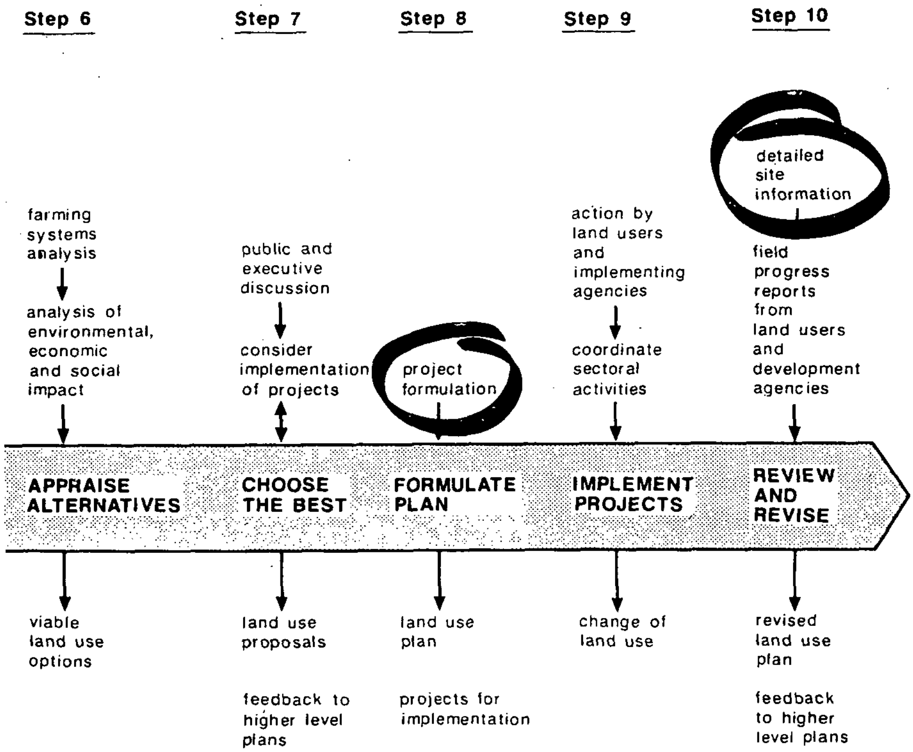


Figure 1 Steps in land use planning, adapted from Dent and Ridgway (1986)



Step 6
Step 7
Step 8
Step 9
Step 10
farming systems analysis
analysis of environmental, economic and social impact
public and executive discussion
consider implementation of projects
project formulation
action by land users and implementing agencies
coordinate sectoral activities
detailed site information
field progress reports from land users and development agencies
APPRAISE ALTERNATIVES
CHOOSE THE BEST
FORMULATE PLAN
IMPLEMENT PROJECTS
REVIEW AND REVISE
viable land use options
land use proposals
feedback to higher level plans
land use plan
projects for implementation
change of land use
revised land use plan
feedback to higher level plans

Step 1 *Decide what you want to achieve.* Establish what is the present situation; find out the needs of the people concerned; agree the goals; specify the terms of reference of the planning team.

Step 2 *Plan to plan.* Organise the work needed; select the team and the methods, arrange facilities.

Step 3 *Identify and structure the problems and opportunities* of the planning area.

Step 4 *Select promising land use types.* Identify or design a range of land use types that might achieve the goals. It is important to cast the net as widely as possible and undertake the widest possible consultation at this stage.

Step 5 *Evaluate land suitability.* For each promising land use type, establish its land requirements and match these with what the land has to offer. For this formal land evaluation, the FAO Framework for Land Evaluation (1978) may be used.

Step 6 *Appraise alternatives.* For each physically sustainable combination of land use and land, assess its wider environmental, economic and social impact.

Step 7 *Choose the best achievable land use.* This is the decision-maker's job in the light of public and executive discussion and the best information that is available at the time.

Step 8 *Draw up a land use plan.* This can take many forms including allocation of land use to land and making provision for appropriate management, or policy guidelines and budgets.

Step 9 *Put the plan into effect.* Action by decision-maker, sectoral agencies and land users.

Step 10 *Learn from the plan.* Monitor progress and revise the plan in the light of experience and to accommodate new goals.

Figure 1 suggests a one-way progression; one step following another in an orderly sequence. In reality this is never the case. Often we have to retrace on steps in the light of experience. For example, Step 6 may reveal unacceptable consequences or there may be opposition to the proposals at Step 7 so that they have to be recast by repeating earlier Steps in the planning process. Always, land use plans have to evolve to meet new circumstances in the planning area, perhaps new demands, perhaps new opportunities.

INFORMATION NEEDS

Direct inputs of natural resources information into the planning process are ringed in Figure 1. The later steps need increasingly detailed information and soil scientists feel most comfortable with the details - phases of soil series, exchangeable sodium percentage, clay mineralogy and so on. Usually, this kind of information is brought into play after the event, to find out what went wrong with a development project, or in the detailed planning of Step 8, for example in the layout of plantations, bunds or irrigation canals. By this stage, the big decisions have already been taken, very often without the benefit of soil information.

Land evaluation

The techniques of land evaluation bring soil and other natural resource information into play earlier in the planning process, in Steps 5 and 6.

Several presentations to this workshop reveal that land evaluation is not a straightforward, mechanical soil survey interpretation. It has to integrate information on agroclimate, topography, soils, farming systems, inputs, outputs and risk.

The first thing to do is to define, the land use for which we are evaluating. This is not simply 'sorghum', or 'cotton'. It is sorghum or cotton grown by a special group of people, in a particular way with specific inputs and specific limitations. 'Sorghum grown as an intercrop with pulses and roots by subsistence farmers using family labour and animal draught' is not the same as 'extensive, mechanised, commercial monoculture of sorghum'. We have techniques to deal with commercial monocultures (for example FAO 1983, 1985). We have not yet worked out how to deal with subsistence multicropping systems but Hackett (1988) has put forward novel ideas that are worth following up.

Good use can be made of detailed soil maps if these are available but, in India, the proportion of the land mapped in detail will remain tiny in the foreseeable future. If decisions have to be made at 1:25 000 then soil maps at 1:250 000 cannot provide the detail we need. How can we reduce the task to manageable proportions?

Few of the data gathered by conventional soil or land resource surveys are actually used in land evaluation (Step 5) or land allocation (Steps 7 and 8) - see, for example, Ive et al. (1985). Rather than map phases of soil series, we might simply map phases of land. There is a research task for the Bureau to identify the minimum data sets needed for different kinds of land evaluation. The land resource component might not include more than probability data for temperature, potential evaporation and rainfall; slope angle; depth to root-limiting layer, soil texture, drainage class and a coarse grouping of parent materials; flood hazard and, in irrigatable areas, groundwater quality.

Having established minimum data sets, simple guidelines for their measurement and use in land evaluation can be prepared at national and regional level for practical application when needed by land users and user agencies. This must be more effective than mapping everything you can think of, in advance of the need, just in case it might be useful.

Land use policy

Information about land resources can be of most value at Steps 1 and 4 which steer the course of future events. Big decisions taken at this stage usually gather momentum of their own regardless of the facts. In the national context, Step 1 is also where the data from the 1:250 000 mapping program could have the greatest impact: not just as baseline information for large development projects but in the formulation of land use policy.

There is no prospect of a handful of land resources specialists directly supporting 100 million farmer decision-makers. It is more realistic to provide key information for high-level policy and decision-making and it seems perverse that this is where we are most unsure of what information is wanted.

The data must be relevant to the decision to be made, so dialogue between policy-makers and natural resource specialists is essential if we are to know what the goals are, what kinds of decisions are made at different levels of decision-making, and what kind of information is needed to support those decisions; and if they are to know what can and cannot be provided. It seems unlikely that 'Typic pellusterts, fine clayey, montmorillonitic' will ever figure in political or economic calculations and it is unreasonable to expect decision-makers, who are not natural resources specialists, to translate our data into useful information. Unscrambling our complex data into single factor maps and standard interpretations, as illustrated by Bullock (this workshop) will certainly make the data more intelligible but I think a more fundamental reappraisal of the information requirements of decision-makers is needed.

Policy goals might include greater regional or national sufficiency in food and fuel; export earnings or import substitution with agricultural products; minimum standards of water supply. Policy-makers need reliable information on the feasibility of the goals, the gains and losses from trading-off one against others, the possible results of interventions through specific land development projects or management of the market. Pioneering work in Canada on synthesising information on the nature and productivity of land with information on goals is described by Smit et al. (1986) and MacDonald and Brklacich (1992).

New tools to systematically measure the ability of the land to sustain specified levels of production and to meet competing demands have three parts: models of the systems of production; mathematical procedures like multiple goal linear programming (which are available commercially, eg. Scicon (1986)); and reliable information on the key components of these models. It is essential that natural resource specialists, agronomists and farming systems specialists are part of the teams that design and use these new tools. Otherwise the tools will be used without knowledge of the quality and limitations of the data, for example the variability engrossed in soil mapping units. Without reliable and relevant data, the output will be of no value to policy-makers or to the community.

REFERENCES

Dent, D.L. and Ridgway, R.W. 1986. *Sri Lanka land use planning handbook.* UNDP/Ministry of Lands and Land Development, Colombo

FAO 1976. *A framework for land evaluation.* Soils Bull. 42, Rome

FAO 1983. *Guidelines: land evaluation for rainfed agriculture.* Soils Bull. 52, Rome

FAO 1985. *Guidelines: land evaluation for irrigated agriculture.* Soils Bull. 55, Rome

Hackett, C. 1988. Matching plants and land. *Development of a general broadscale system from a crop project for Papua New Guinea.* CSIRO Div. Water and Land Resources, Natural Resources Series No. 11, Canberra.

Ive, J.R., Davis, J.R. and Cocks, K.D. 1985. LUPLAN: A computer package to support inventory, evaluation and allocation of land resources. *Soil Survey and Land Evaluation* 5,3, 77-87

MacDonald, K.B and Brklacich, M. 1992. Prototype agricultural land evaluation systems for Canada I. Overview of systems development, II selected applications and prospects. *Soil Use and Management* 8,1, 1-15

Scicon 1986. SCICONIC/UM User guide, version 1.40. Scicon Ltd., Warendon Tower, Milton Keynes, MK17 8LX, U.K.

Smit, B., Brklacich M., Dumanski, J., MacDonald, K.B. and Miller, H. 1986. Integrated land evaluation and its application to policy. *Soil Survey and Land Evaluation* 6,3 99-113

TECHNICAL SESSION ON METHODS OF LAND RESOURCES SURVEY

SOME APPLICATIONS OF GEOMORPHOLOGY IN SOIL SURVEYS FOR LAND USE PLANNING

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INTRODUCTION

Soil survey poses numerous methodological problems. First, there is the crucial question as to what kind of mapping units are to be distinguished, given the many alternative possibilities. Then the overriding dilemma is that almost all soil characteristics, hidden below the ground surface, are not readily perceived and measured - which makes the associated field and laboratory work arduous, time-consuming and costly. Major difficulties of sampling design, extrapolation and mapping stem from this, because in reality only a minute fraction of the total soil body can be examined. In view of the resultant fragmentary information, the identification and delimitation of mapping units must involve a considerable degree of conjecture if based on the soil data alone. Furthermore, soil properties vary continuously in space, so any mapping unit will have internal variability.

This paper summarises a method of using geomorphological criteria as a framework for mapping soils. It is based on the concept of geomorphological "sites" which has three main postulates (Wright 1972a, 1973). First, the ground surface can be differentiated into relatively uniform slope units termed "sites". Second, closely similar sites - "site types" - tend to recur within particular localities, so spatial groupings of sites can be delimited - "site assemblages" - each dominated by a few characteristic site types. Finally, sites and site assemblages constitute ecological entities with an internal unity of ground climate, hydrology, soil characteristics and plant habitats.

Such geomorphologically-defined entities can provide a framework for soil mapping. There are considerable practical advantages because surface form is more readily perceived, measured and interpreted than most other terrain features. Hence geomorphological differentiation of soil-slope units can greatly facilitate identification and extrapolation of the corresponding soil changes. Moreover, any such unit is associated with a distinctive combination of natural process conditions - which makes this approach to soil mapping of particular relevance in soil surveys for land use planning and environmental management.

LANDFORM AND SOIL RELATIONSHIPS

There are close relationships between soils and landforms, linked to the interconnections between landforms and bedrock geology, landforms and hydrological systems, landforms and ground climate. Geomorphological features are expressive of underlying parent materials and the nature and duration of the geomorphic processes that have produced the associated landforms. Detailed slope characteristics reflect, for example, the rate of production of rock weathering products relative to their removal, which varies according to the properties of the rock and the weathering and transporting agencies at work on the slope. Within any locality, therefore, each lithology tends to have a characteristic range of slope forms and gradients. There are similarly close associations on a regional scale, with changes in lithology and structure being etched into different major relief forms.

Ground shape is not just a product of land-forming processes, however, but is itself an important factor influencing the achievements of the processes. Thus the vigour of these processes depends on the downslope component of the force of gravity, which varies locally in relation to slope characteristics. Moreover, the angle, aspect, curvature, micro-relief and local elevation of a slope influence the amount of incident solar radiation, humidity, ground temperature and hydrological conditions. On a broader scale the spatial pattern and dimensions of interfluves and valleys govern regional variations in precipitation, temperature, winds, thermal currents, watertable relationships, surficial water movements and land drainage. In such ways, landform characteristics influence local and regional changes in rainfall runoff and infiltration relationships, ground climate, and the nature and intensity of weathering, eroding and transporting agencies (Wright 1984).

The interconnections outlined above underlie the co-relationships between landforms and soils. Physically inseparable, slopes and soils share common parent material and processes of development. In particular, slope variations influence the effects of atmospheric agencies at the ground surface, and so local weathering contrasts are associated with geomorphological differences. Furthermore, just as slope evolution is a function of the rate of production of weathering products relative to their removal, so this relationship also governs the degree of contemporaneous soil formation. Moreover, throughout this evolution slopes and soils develop interdependently, because soil characteristics equally with ground shape are an important factor influencing the achievements of slope-forming processes. For such reasons local geomorphological differences are associated with soils changes.

The interconnections are not necessarily simple and clearcut. Individual soil characteristics have complex patterns of spatial variation in relation to one another and with respect to the associated slope characteristics While there can be no simple solutions to understanding the complexity of spatial variations in soils, geomorphology has practical advantages in providing a framework to facilitate the objective mapping and investigation of that complexity.

GEOMORPHOLOGICAL SITES

The concept of geomorphological sites and the technique of site analysis were evolved initially as an approach to land classification (Wright 1972b). Geomorphological sites are small slope units of uniform shape internally, regularly curved or near-planar, and delimited externally by relative discontinuities in gradient or rate of change of gradient (Wright 1973). On the basis of site analysis, broader terrain units can be identified at different levels of abstraction, built-up systematically by aggregation of the classified individuals. This procedure is facilitated because, in any locality, the spatial distribution of sites comprises a mosaic of small areas, each typified by repetition of a few characteristic "individuals" which reflect a unity of underlying parent material and history of land-forming processes. Consequently, the broader terrain units referred to above can be compounded on the basis of only limited sampling of their recurring "individuals".

Site analysis provides an appropriate framework for soil mapping, because sites and site assemblages are ecological entities and such local geomorphological variations tend to be associated with changes in important soil properties including depth, physical and chemical properties, profile development, moisture relationships and erodibility. These site and soil relationships have been demonstrated in many studies, a wide-ranging example being that of Sitorus (1983).

SURVEY PROCEDURES

Airphoto interpretation

Accuracy and cost-efficiency in soil surveys are greatly dependent on the use of airphotos and other forms of remote sensing. The present scheme uses conventional black and white photography as the interpretative and mapping base: this is probably the best general-purpose imagery, is relatively economic and widely available. Airphoto interpretation enables large areas to be surveyed comparatively speedily even though field sampling is based on detailed site analysis. Moreover, such interpretation facilitates an integrated methodology for the study of landscape interrelationships. This is essential for land use planning and environmental management, both of which need soil information.

Geomorphological interpretation of airphotos is widely used in surveys of land resources, including soil surveys (Wright 1984), though site analysis provides a rather more detailed and more systematic approach to the study of landform and soil relationships that is usually the case in such surveys, as illustrated by Wright (1972a), Wright and Wilson (1979) and Sitorus (1983). Nevertheless, an advantage of this approach is that it is equally applicable in either intensive or broad-scale projects. The scale of airphotos to be used is an important consideration and, from experience in a range of environments, the writer advocates a scale of 1:20 000 for most surveys, though 1:50 000 may be adequate in some cases. The procedures outlined below are greatly facilitated by the use of stereoscopes with binocular magnification.

Airphoto interpretation is a major activity throughout the survey programme. Prior to fieldwork it guides the selection of sampling localities and the planning of traverses. During fieldwork it provides - most importantly - a reference base for recording, collating and evaluating all observations. During and after fieldwork the extrapolation of data on the basis of airphoto interpretation enables much larger areas to be mapped and described than would be possible otherwise. In all stages, geomorphological interpretation of airphotos has much to contribute because landform characteristics are usually identified more readily and in greater detail from airphotos than geology, soils and many aspects of vegetation. The most subdued site changes, however, rather than being directly perceived by stereoscopic inspection of airphotos, tend to be reflected by tonal contrasts - that is difference in brightness between the image and its background - which are commonly associated with detailed differences in slope form, surficial materials and drainage relationships. Surface micro-relief, for example, which is expressive of distinctive slope processes and materials, contributes to such tonal contrasts because the scattering of light rays caused by an irregular surface produces some darker shade of grey than similar, but smoother ground.

Changes in the composition, colour and water content of surficial materials are particularly influential too. Airphoto tones are also governed by local vegetation contrasts and, because these latter reflect habitat variations - which are closely related to geomorphological site differences - these differences tend to be accentuated by subtle vegetation changes. For these various reasons, geomorphological site variations are commonly perceptible by airphoto interpretation, though, as explained below, the accuracy and detail of the perception is largely dependent upon the amount of such interpretation that is actually carried out in the field, underpinned by ground-truth data.

<u>Sampling design</u>

The main objectives in preparing for fieldwork are, first, to learn as much as possible about the survey area from the available information and from the study of the airphotos; second, to draw up a network of field sampling localities in order to cover adequately all types of terrain within the area.

Completely random or rigorously systematic sampling is uncommon in soil surveys. Sampling is usually guided by variations in landscape features known to be related to soil changes, and progressively refined until the mapping attains the desired level of detail. Thus major relief and geology differences generally provide the framework for soil mapping at a broad scale, followed by more intensive analysis of the main landform units. Diverse techniques are available for mapping and spatial analysis in geomorphology (Cooke and Doornkamp 1990, Goudie 1990). In most surveys of soils or surficial materials, however, the mapping framework consists of morphological or morphogenetic landform "types" delineated on the basis of airphoto interpretation (Wright 1984). Alternative procedures to that outlined below can be devised for special purpose surveys, perhaps involving more refined remote sensing such as infrared imagery and computerised digital mapping models. The present procedure is advocated because, first, it is straightforward and relatively inexpensive to apply; second, it has multipurpose applications; third, it has proved to be suitable for surveys at different scales and in a range of climatic and land use situations; finally, it provides a precise, systematic method of soil mapping based upon logical principles of land classification.

In preparing, for fieldwork the airphotos are laid down in stereoscopic pairs of prints to form an uncontrolled mosaic of the survey area. A stereoscopic appraisal is then made of their constituent "tonal elements" - the smallest areas that can be recognised as having uniform tones. An "airphoto pattern" is identified as having a distinctive variety of tonal elements but characterised by repetition of a limited range of those elements. After only a little experience, the interpreter can differentiate such patterns relatively easily because groups of closely similar elements always tend to recur together. The procedure is as follows. A point is selected on an airphoto, its corresponding tonal element is identified and, by stereoscopic interpretation, its ground characteristics are inferred (especially those relating to geomorphology, soil, geology, vegetation/land use). The interpretation is then extended outwards to the adjoining tonal elements which are examined as before. The procedure is repeated to recognise and interpret the most common tonal elements of that locality. Areas dominated by repetitions of a few types of tonal elements are regarded as airphoto patterns;

their boundaries coinciding with the appearance of a different combination of recurring tonal elements and the disappearance of the previous combination.

Each tonal element will be associated with one or more geomorphological sites on the ground, and the airphoto patterns identified in this way will consequently represent a specific combination of sites. It is most important, however, to clearly distinguish between the units recognised on the airphoto (tonal elements and patterns) and the taxonomic units (sites and site assemblages) to be recorded and mapped eventually. It is only through fieldwork that one can establish the precise airphoto relationships of the sites to be identified on the ground, and of the site assemblages to be subsequently delimited on the basis of the classified site types. The airphoto patterns are distinguished provisionally at this stage primarily for planning of subsequent sampling in the field.

Detailed mapping of airphoto pattern boundaries is not attempted before fieldwork, therefore, because there will be no simple spatial correlation between them and the site assemblages which - as units of the ground, not of airphotos - must be differentiated in the field. Instead, the inferred characteristics of the airphoto patterns and their dominant tonal elements are recorded. In addition, for cross-reference purposes and ease of visual recognition, each pattern is allocated a shorthand set of symbols (alphabetical letters) which are marked on corresponding parts of the airphotos. The symbols should incorporate references to geology and geomorphology because they are important diagnostic characteristics of ground environments. Symbols are also included, where feasible, for soils and vegetation/land use. These symbols are only provisional initially, but become a useful cross-reference system as they are refined during fieldwork.

Based on such intensive airphoto interpretation, a stratified network of field sampling is planned. The sample localities are chosen to cover the range of tonal elements in the main airphoto patterns, with particular emphasis on the dominant elements - those which are most frequently recurring and/or most extensive. These localities and traverses between them are plotted on the airphotos in "omnichrom" pencil, or something similar, which can be easily erased when alterations and refinements are made on the ground.

Soil site analysis

It is vital in the field that exact relationships are established between the location of each soil pit or other soil observation and the boundaries of the corresponding site and airphoto tonal element. Detailed understanding of airphoto characteristics - and the ability to extrapolate field data on that basis - is a function of the amount of intensive airphoto interpretation that is carried out on the ground. At all times during fieldwork, therefore, the survey team must be absolutely certain of its precise location on the airphoto. With practice this is not difficult, simply requiring continuous, careful navigation using the airphoto.

Airphoto interpretation is a crucial part of fieldwork. It draws attention to possible site variations in all localities; it indicates which tonal elements still need to be examined by reference to information already obtained from sampled sites; in the later stages of fieldwork it enables unsampled areas to be mapped on the basis of extrapolations from sampled areas. On reaching a sample locality, the tonal elements previously differentiated in planning fieldwork are recognised carefully in terms of their ground relationships. According to the complexity or otherwise of the ground surface as perceived in this way, it may be decided to examine fewer or additional airphoto elements. A point is then selected in the centre of a patch of ground which appears to be sufficiently uniform in surface form, surficial material and vegetation as to probably fall within one geomorphological site (ie. a near-planar or regularly curved slope element). The site chosen should preferably be a frequently recurring or relatively extensive 'individual' in that locality. A measured slope profile, aligned through that point, is then planned so as to pass through its corresponding tonal element and the adjoining tonal elements which need to be sampled. If it is not possible to cover all such elements along one slope profile, additional profiles are planned.

The above mentioned starting point is marked precisely on the airphoto. The first soil profile is dug there and the relevant information recorded. From this point the geomorphological record is extended along the measured slope profile to delimit the boundary of the initial site and its neighbours by careful slope measurements. In so doing the primary criterion for site delimitation is the internal uniformity of slope form rather than the existence of abrupt external discontinuities, because delimiting discontinuities may be only slight slope changes (Wright 1973). The positions of the identified sites in relation to the associated tonal elements are carefully marked in ink on the airphoto.

The characterisation of sites along the slope profile is as follows. Ranging poles are placed at survey stations at fixed intervals (5-15 m, depending on the scale of work) in the direction of greatest slope. The minimum size of sites to be delimited is 15 m. The angles of slope between successive stations are measured using a Clinometer or Abney level in moderately or steeply inclined terrain, and a surveyor's level in gently-sloping plain lands. Sites are identified as slope segments which are near-planar or regularly curved, whose boundaries are relative discontinuities in gradient (for planar sites) or rate of change of gradient (for curved sites). The characteristic gradients for individual sites are computed as those of the centrally-placed measured segments. Curvatures are calculated as degrees of change per metre, concave curvatures having a negative sign and convex ones having a positive sign.

Local slope variations less than the size of 15 m (eg. hummocks, rills, terracettes, gullies) are measured and recorded. Such micro-relief is a distinctive feature of many sites and gives insight into slope-forming processes. Slope orientation, or aspect, is measured using a magnetic compass. Slope materials are recorded in terms of three distinctive groups - bedrock, finely-divided materials, and coarser rock fragments as described by Wright (1973).

Soil observations are taken within each site or, where the available time prevents this, in those individuals that are most representative of the locality - as judged on the ground and by airphoto interpretation. Inferences about natural processes are recorded by reference to the nature of weathering products, erosion, transport and deposition of slope materials. These inferences are useful in the eventual appraisal of the survey data, and in making recommendations for more intensive investigations relevant in environmental management, for example. The spatial relationships of the sites are recorded in an annotated sketch or block diagram of each sample locality and its surroundings, with brief morphometric notes and other records to illustrate the geomorphological and geological setting.

At base camp the data are organised as follows. All information for each geomorphological site is transferred on to a tabular summary sheet for each sample locality. A simple block diagram is added to illustrate the terrain relationships of the sites. The shorthand symbols previously allocated to the associated airphoto pattern are refined in the light of the field data and utilised subsequently to refer to the type of terrain in the sample locality as well as to that part of the airphoto pattern.

The sample locality summary sheets are progressively combined into groups based on the terrain symbols given to them. This grouping procedure is accompanied by further airphoto interpretation and data extrapolation to confirm the terrain unity of each group and its spatial occurrences on the airphotos. By comparison of the individual sites recorded in such groups of sample localities, "site types" are identified - each being a group of sites which closely similar characteristics. A "site assemblage" can then be delimited on airphotos as an area or areas dominated by members of one site type or of two or more closely interspersed site types. The characteristics used to differentiate site types are gradient, curvature (representing slope form), texture of surficial material and depth to bedrock (representing slope composition). Evident contrasts in these differentiating characteristics enable the majority of site types to be readily identified. However, the possible ecological importance of the most subtle site differences may need to be assessed also in terms of other criteria including, for instance, slope aspect and position in toposequence (which are associated with local changes in ground climate and surficial water systems), and soil colour (which is expressive of parent materials and weathering relationships, for example).

By reference to the terrain groupings of the sample locality summaries, airphoto patterns are re-examined in terms of the spatial occurrences of site types in order to identify site assemblages as areas dominated by members of one site type or of two or more closely interspersed types. This is an ongoing procedure which is progressively refined as site records and other ground-truth data are accumulated. In conjunction with this, additional sampling localities are planned specifically to test the accuracy of airphoto extrapolations of existing data in interpreting the geomorphological sites of those localities prior to sampling them. Such continual cross-reference to existing site data, and the testing of interpretations of the corresponding airphoto characteristics, is essential in developing accurate extrapolation of data, thereby enabling the mapping of site assemblages to be extended on the basis of airphoto interpretation.

In the later stages of fieldwork, therefore, when many site types have been identified and compounded into site assemblages, these assemblages are mapped progressively on the airphotos, in the field, in and around the completed sample areas. Plotting of the boundaries is then extended along field traverses outwards from sample areas, data from the latter being extrapolated through detailed airphoto interpretation and ground survey (Wright 1972a). It is essential that such extrapolation be implemented in the field. During this mapping phase, further sample localities may be planned to ensure that adequate information is collected for each of the identified site assemblages.

<u>Post-fieldwork</u>

This stage involves the following activities to finalise the mapping.

1. The airphotos are again laid down to form a mosaic of the survey area, and re-examined to ensure that all sample localities are marked on them and clearly annotated, together with site assemblage boundaries mapped in the field.

2. The descriptions of the main site types are finalised for each site assemblage. More complete accounts of these latter mapping units are compiled in tabular form from field records, incorporating the chief features of each constituent site type in terms of geomorphology and soils

(together with any other data, such as vegetation and land use, that may have been recorded in the survey).

3. The site assemblage boundaries are finalised by retracing under the stereoscope the traverse networks marked on the airphotos, and re-examining the delineated boundaries along them in terms of sample data and corresponding airphoto interpretation. This involves verification of the spatial patterns of occurrence of the dominant site types in each assemblage, by reference to their correlations with the associated tonal elements that had been established on the ground. Here it must be emphasised again that sampling in the field and associated delimitation of site assemblages are based on the identification of the dominant site types. These provide the diagnostic criteria for mapping assemblages.

SOIL VARIABILITY

The present approach to site analysis and mapping, based on logical principles of classification, has major advantages over the more conventional subdivision of an area into landform regions and then collecting soil data within those regions. Firstly, mapping units are likely to have much greater internal unity if built-up from within by aggregation of classified sites - equivalent to the taxonomic individuals of classification theory. Secondly, such mapping units are much more likely to be differentiated at a consistent level, or category, of classification. In contrast, by the method of subdivision it is most improbable that mapping units can be delimited consistently at any one level. Indeed these subdivisions may vary greatly in degree of internal diversity.

The evaluation of soil variability is a crucial requirement in this context. Soil characteristics vary continuously in space, so any mapping unit will have internal variability. However, areas of soil grouped into one class of mapping units should be closely similar with respect to the classifactory properties and thus have an equivalent degree of internal variability in terms of those properties. Wright and Wilson (1979) proposed a statistical model, therefore, to evaluate such variabilities and to compare and classify soil mapping units on that basis. In this way it can be ascertained, for example, whether areas grouped within one mapping unit do in fact belong together; equally, areas which should be combined within one group can be identified.

LAND EVALUATION AND LAND USE PLANNING

Multi-purpose mapping

Soil surveys are but stages, albeit of fundamental importance, in the process of land evaluation for the planned use and management of resources. Geomorphological applications can also enhance the value of the surveys in relation to that process, as follows. In site analysis, soil and geomorphological data are recorded jointly within each site at the scale of the immediate vicinity of the soil pit. Close integration of both sets of data at a consistent scale is achieved; therefore, in contrast to those surveys having much more generalised geomorphological information at the scale of the landform region, making it impossible to equate the individual soil variations with the geomorphological generalities. Such integration of observations can also include the measurement of other kinds of data so that the survey findings can be used for different purposes - agricultural planning, engineering evaluation, and environmental management, for instance.

Much additional data can be collected by the soil survey team itself. Terrain evaluation for engineering purposes, for example, requires detailed geomorphological information together with soil data in appropriate forms - specific particle size classifications, uniformity coefficients, plasticity characteristics, density indices, shear strength, and so forth. All of these data could be integrated within the framework of site analysis and the resultant site-assemblage mapping - such geomorphological units being ideally suited for engineering evaluations, sample planning and extrapolation of laboratory findings (eg. Black, article in Coates 1973; Kreig and Rogers, article in Coates 1976).

Many aspects of land evaluation must be multi-disciplinary, however, in which case site types and site assemblages provide the common spatial framework needed for integrated collaboration between different specialists - which otherwise can be a methodologically difficult problem (Wright 1987). The data required by other specialists can be gathered by them during the soil survey or in follow-up stages. These latter are commonly necessary to increase the practical value of surveys - as in the production of the Soil and Land Resources Atlas of India by NBSSLUP. Geomorphic research can make valuable contributions here too - in a more thorough investigation of soil-slope units in relation to degree of erosion and slope stability, for example. As ecological units, geomorphological site types and site assemblages again provide a logical framework for planning these follow-up investigations and - as in other respects - for extrapolating their findings.

<u>Analysis of soil variability for land evaluation</u>

Where agricultural development is the ultimate concern, expediencies are needed to speed up the soil surveys so that effort can be concentrated in the subsequent land evaluation studies, while producing multi-purpose mapping units that are suitable as a common base for those varied studies. Consequently, there is a need for mapping units which - as in the present system - can be identified relatively quickly and can be adapted in diverse ways as may be required later. Implicit also here is the need for objective, numerical analysis which is particularly important in soil survey for land evaluation (Wright 1977). The information collected in any survey is inevitably fragmentary, so it is essential to maximise it value. This is much facilitated by numerical data because they are readily organise and analysed systematically; with statistical handling of the data enabling rigorous testing of research hypotheses. There are also practical advantages arising from the objective sampling needed in numerical analysis, which can lead to greater speed, greater accuracy and reduced costs by comparison with more traditional intensive surveys that strive for "complete" coverage of a study area. Finally, numerical techniques provide a common methodology to facilitate the integration of multi-disciplinary effort, which is all important in land evaluation (Wright 1987).

These points were illustrated by Sitorus (1983) who assessed the relevance of the site analysis approach to land evaluation in part of the south-east Spain. The USDA capability classes, for instance, were found to be relatively broad terrain subdivisions by comparison to the site assemblage mapping, and any of them was likely to contain soil variations of agricultural importance. Within a capability class it was possible, in fact, to identify mapping units (a group of site assemblages) which were essentially the same with respect to specific soil properties, and other groups of assemblages which were quite different with respect to those properties. Sitorus demonstrated that such similarities and differences could be expressed precisely in statistical terms, thus enabling numerical classification of the mapping units.

The implications were considerable. Application of the USDA scheme required lengthy fieldwork, including detailed soil survey to delimit subclasses and units. At a scale of 1:50 000, soil maps with conventional legends in terms of modal and limiting soil profiles, for instance, were extremely time-consuming to produce. In contrast, the site analysis procedure achieved a similar endpoint relatively speedily, in that the site assemblages and their constituent site types differentiated detailed soil variations in terms of many properties important for agricultural purposes. Furthermore, numerical classification of these mapping units, as applied by Sitorus, could then enable information on soil-crop relationships or crop management requirements to be extrapolated within a proposed development area on the basis of existing knowledge or from planned experiments.

Investigation of natural process systems

Ideally the findings of soil surveys should be in forms directly applicable to land evaluation and management. Often, however, a fundamental reappraisal of traditional land use is needed, which involves a variety of activities after the preliminary survey: research into the biological and physical possibilities of agricultural production; practical tests of the results; social and economic assessments; and so forth (Wright 1972a). Most importantly, the land evaluation research must seek understanding of natural process systems so that the effects of human activities may be predicted and management planned accordingly.

Much basic research may need to investigate natural processes governing primary productivity: including nutrient cycling and micro-climatic agencies; associated crop and animal trials; responses to soil treatments and management practices. Such varied investigations can only be extremely localised in their field situations, so their design and deployment must be planned carefully. Logically, the research should be concentrated in geomorphological site types and site assemblages which portray the range of conditions in the study area, with emphasis on those assemblages which characterise more extensive or more promising tracts of country. Conversely, the assemblages provide a framework for extrapolating the results of the research throughout the wider planning area. A variety of statistical and other techniques is available to refine such extrapolation (Wright 1972a, 1987).

Studies of geomorphological process systems are also of central concern in relation to the appraisal of hazards, environmental monitoring and land use impact assessment. The relevance of investigations into soil erosion, slope instability and failure, river systems and flooding is manifestly evident. Site assemblages and their constituent site types again provide an appropriate framework within which to plan field experiments and monitoring of these hazards, and subsequently to extrapolate the findings, including appropriate management techniques, systemically over larger areas.

Field-based investigations and supporting laboratory work may vary greatly (Cooke and Doornkamp, 1990; Goudie 1990) but a multi-purpose strategy with special relevance should be mentioned here. The drainage catchment (alternatively referred to as a watershed or drainage basin) traditionally has been the inescapable unit for hydrological/geomorphological studies and more recently for environmental research, including land use impact and management. Of particular interest here is experimentation into the effects on soil and water resources of different kinds of land use, and the associated development of multi-resource management schemes (Gaskin et al. 1983; Burt and Walling 1984; Swank 1986). Such integrated catchment research may be complex and costly. It is feasible, however, to devise methodologically simpler projects - with important practical applications - that could be carried out by the NBSSLUP as part of their land evaluation and land use planning work. Examples include the experiments of Heathwaite et al. (1990a, 1990b) who monitored the effects of different land uses on runoff, soil sediment and nutrient losses and their delivery to streams. The resultant management implications related to soil-crop-sediment loss relationships, fertilizer applications and nutrient losses with regard to land use practices, and stream water quality control.

CONCLUSIONS

In soil surveys, geomorphological site analysis can facilitate the planning of data collection and the mapping of soil variations. It enables the ground to be covered more speedily than might be possible otherwise, and produces mapping units that is likely to be more internally consistent than in surveys based on other forms of "purposive" or subjective sampling and mapping.

Because of the environmental relationships of the soil-sites and site assemblages, the approach produces a framework of multi-purpose mapping units that can be used for a variety of land classifications and evaluations, and for the integration of the multi-disciplinary inputs essential in development projects.

Finally, geomorphology focuses the dynamics of systems, their environmental relationships - including land use factors - and their spatial and temporal changes. Such investigations are important in environmental management, because sound management requires that human impacts upon those systems can be predicted so that land uses can be planned accordingly.

REFERENCES

Burt, T.P. and Walling, D.E. (eds.) 1984. Catchment Experiments in *Fluvial Geomorphology*. Geo Books, Norwich, U.K.

Coates, D.E. (ed.) 1973. *Environmental Geomorphology and Landscape Conservation, III: Non-Urban Regions*. Dowden, Aitchinson and Ross, Stroudsberg, U.S.A.

Coates, D.E. (ed.) 1976. *Geomorphology and Engineering*. Dowden, Hutchinson and Ross, Stroudsberg, U.S.A.

Cooke, R.U. and Doornkamp, J.C. 1990. *Geomorphology in Environmental Management*. Clarendon Press, Oxford, U.K.

Gaskin, J.W., Douglass, J.E. and Swank, W.T. 1983. Annotated Bibliography of Publications on Watershed Management and Ecological Studies at Coweeta Hydrological Laboratory, 1934-1984. USDA Forest Service, Southeastern Forest Experiment Station, General Technical Report SE-30. Ashville, North Carolina, U.S.A.

Goudie, A. (ed.) 1990. *Geomorphological Techniques*. Unwin Hyman, London, U.K.

Heathwaite, A.L., Burt, T.P. and Trudgill, S.T. 1990a. Land-use controls on sediment production in a lowland catchment, southwest England. In J. Boardman, I.D.L. Foster and J.A. Dearing (eds.), *Soil Erosion on Agricultural Land*. Wiley, London, U.K.

Heathwaite, A.L., Burt, T.P. and Trudgill, S.T. 1990b. The effect of land use on nitrogen, phosphorous and suspended sediment delivery in streams in a small catchment in southwest England. In J. Boardman, I.D.L. Foster and J.A. Dearing (eds.), *Soil Erosion on Agricultural Land*. Wiley, London, U.K.

Sitorus, S.R.P. 1983. *The Analysis of Soil Variability for Land Capability Assessment*. Ph.D. Thesis, University of Sheffield, U.K.

Swank, W.T. 1986. Biological control of solute losses from forest ecosystems. In S.T. Trudgill (ed.), *Solute Processes*. Wiley, London, U.K.

Wright, R.L. 1972a. Perspective in environmental research for land use planning in developing countries. *Geoforum*, 10:15-33

Wright, R.L. 1972b. Principles in a geomorphological approach to land classification. *Zeitschrift fur Geomorphologie*, 16:351-373.

Wright, R.L. 1973. An examination of the value of site analysis in field studies in tropical Australia. *Zeitschrift fur Geomorphologie*, 17:156-184

Wright, R.L. 1977. On the application of numerical taxonomy in soil classification for land evaluation. *ITC J.*, 3:482-510.

Wright, R.L. 1984. Applied Geomorphology. In C.W. Finkl (ed.), *The Encyclopedia of Applied Geology*. Nostrand Reinhold, New York, U.S.A.

Wright, R.L. 1987. Integration in land research for Third World development planning. *Landscape Ecology*, 1:107-117.

Wright, R.L. and Wilson, S.R. 1979. On the analysis of soil variability. *Geoderma*, 22:297-313.

SLOPE MASS MOVEMENTS AND SOILS IN PART OF THE NORTH-EAST REGION OF INDIA

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INTRODUCTION

This article outlines a method for the collection and mapping of soils data in the context of their geomorphological relationships. Such an approach has considerable practical advantages. For example, extrapolation of soil characteristics on the basis of geomorphological relationships greatly facilitates soil mapping because these relationships can be readily identified on the ground and by airphoto interpretation. Also, the geomorphological associations of soils, including geomorphic process relationships, are of central importance in land evaluation for environmental management and land use planning.

The study was carried out in the north-east region of India whose hilly and mountainous zones are typified by slope instability due to mass movements of slope materials as well as vigorous erosion. Such mass movements consist of all gravity-induced movements except those in which the material is carried directly by transporting media such as ice, snow, water or air, when the processes are termed mass transport. They range from very slow deformations of materials, termed creep, to relatively rapid types such as falls, slides and flows (Varnes 1978). The term "stress" is used for the motivating force, "strength" for the resistance opposing that force, and "strain" for the resulting deformation (Finlayson and Statham 1980). Varnes (1978), therefore, considered the causes of these movements in two broad groups: factors that contributed to increased shear stress, and factors that contributed to reduced shear strength.

The most common type of mass movement related to the present study is landslides, whose mechanisms involve both 'external' and 'internal' processes (Terzaghi 1950). Diverse environmental factors involved are climatic, geological, hydrological and ecological conditions and, not least, human land-use activities (Carson 1976, Johnson and Wathal 1979, Chorley et al. 1984, Wright 1984, Gregory and Walling 1987).

STUDY AREA

The area, between latitudes 26°20′ and 27°50N and longitudes 94°10′ and 96°20′E, covers parts of the states of Arunachal Pradesh and Nagaland within the Lower Himalayan region, and Assam within the Indo-Gangetic plains. The hills are underlain by folded and faulted sedimentary rocks, mainly sandstones and shales, but schist and gneiss with granite intrustions in some localities. The plains consist of more recent thick alluvial deposits.

The pronounced slope instability is a result of various factors including high rainfall amounts, steep slopes on unstable bedrock formations, and intense fluvial activity. The extensive hilly tracts of the area receive very heavy rainfall (more than 3000 mm)*. In the higher mountains most of the precipitation is in the form of snow which augments surface flow only after March when snow melt begins.

METHODS

Investigations started with airphoto interpretation to identify slope instability conditions and to plan field observation areas in specially vulnerable locations. Geomorphological site analysis was carried out in these areas and, within that framework, information was collected about the related mass movement conditions and their associated soils. Geomorphological "sites" are identified by differentiating slopes into near-planar or regularly curved segments, each with an internal unity of surficial material. This is done along measured slope profiles, aligned in the direction of maximum gradient, with equally-spaced survey stations at 5-15 m intervals, depending on terrain complexity and the scale of analysis. A minimum of three contiguous measured lengths along such a profile within a site is needed to quantify curvature, hence the minimum size of sites delimited in detailed work is 15 m. A slope segment less than this size is regarded as a local irregularity within a site. Such geomorphological sites are ecological units each having an internal unity of micro-climatic and soil conditions, with an associated limited range of habitat for plant response - all of which reflects a unity of parent material and slope-forming processes (Wright 1972, 1973, 1984). Consequently, site changes within any locality are reflected in subtle tone contrasts on airphotos. In site analysis, therefore, fieldwork is planned on the basis of airphoto interpretation to identify "tonal elements" - the smallest areas on airphotos which can be recognised as having uniform tones. Any individual tonal element will correspond to one or more distinctive sites on the ground. Equally, groups of similar tonal elements tend to recur together, forming airphoto patterns, each pattern corresponding to a specific combination of geomorphological sites. The identification and interpretation of such tonal elements and airphoto patterns enabled field sampling localities to be selected to cover the more representative, more frequently recurring, geomorphological site conditions within the study area.

* *Footnote. References to rainfall amounts here and subsequently are taken from Directorate of Economics and Statistics, Statistical Handbook published by different state Governments of Arunchal Pradesh, Assam and Nagaland.*

RESULTS

Bishi, Rupai area

This area is in the Lohit district of Arunchal Pradesh which consists of hills and mountains at 150-5000 m above sea level. It receives very heavy rainfall, the annual amount at Tezu during 1984 being 3500 mm, though it can be up to 6400 mm.

Site analysis was carried out along a measured slope profile about 370 m long (Figure 1(i)) which consists of steep, forested hills of sandstone and shale with some conglomerate. The higher part of the profile consists of site A, gradient 60-70%, with rills and incipient gullies commonly upto 15 cm wide and 30-60 cm deep. There are slope wash deposits of a few cm thickness over bedrock. Small terracettes upto 10 cm across have been eroded in association with the slope wash. There is a pronounced concave slope discontinuity downslope - from 58% to 15% - beyond which site B, gently concave 11-16%, consists of gravelly deposits containing boulders, cobbles and pebbles. Downslope from this deposit is a near-planar site C, 8.7-10.5%, whose distal boundary is an angular inflexion from 8.7% to 6.1%, the slope then declining into site D, 5-6% along the margins of the river. The surface texture of this latter, gently inclined planar site is silty clay loam.

Mass movements here are mainly slides and topples (as defined by Hutchinson 1986). The underlying shales are exfoliated along the cleavage, providing easy access to rain water. In the steeper higher part, with water as a lubricating agent and with associated changes in pores water pressure, the effects are to increase shearing stress and initiate mass movements. In addition, frequent seismic activity, and also blasting or road construction, induce rapid, transitory changes of stress in all slope materials and thus overall increases of shearing stress. Moreover, because sites B and C, especially, include talus and colluvial sand and gravel, there is decreased cohesion and increased shearing stress which also induces slope instability.

The soils of the steeper, higher site A of this slope profile are moderately deep, excessively drained, very dark greyish brown, coarse loamy and acidic. The slope materials brought down from this site by mass movement and wash into the concave site B are associated with very deep, well drained, stony soils with a matrix that is brownish yellow to yellowish brown, fine-textured and medium acidic. Soils in the near-planar lower sites C and D are very deep, imperfectly drained, grey, fine loamy and slightly acidic - more stony in site C.

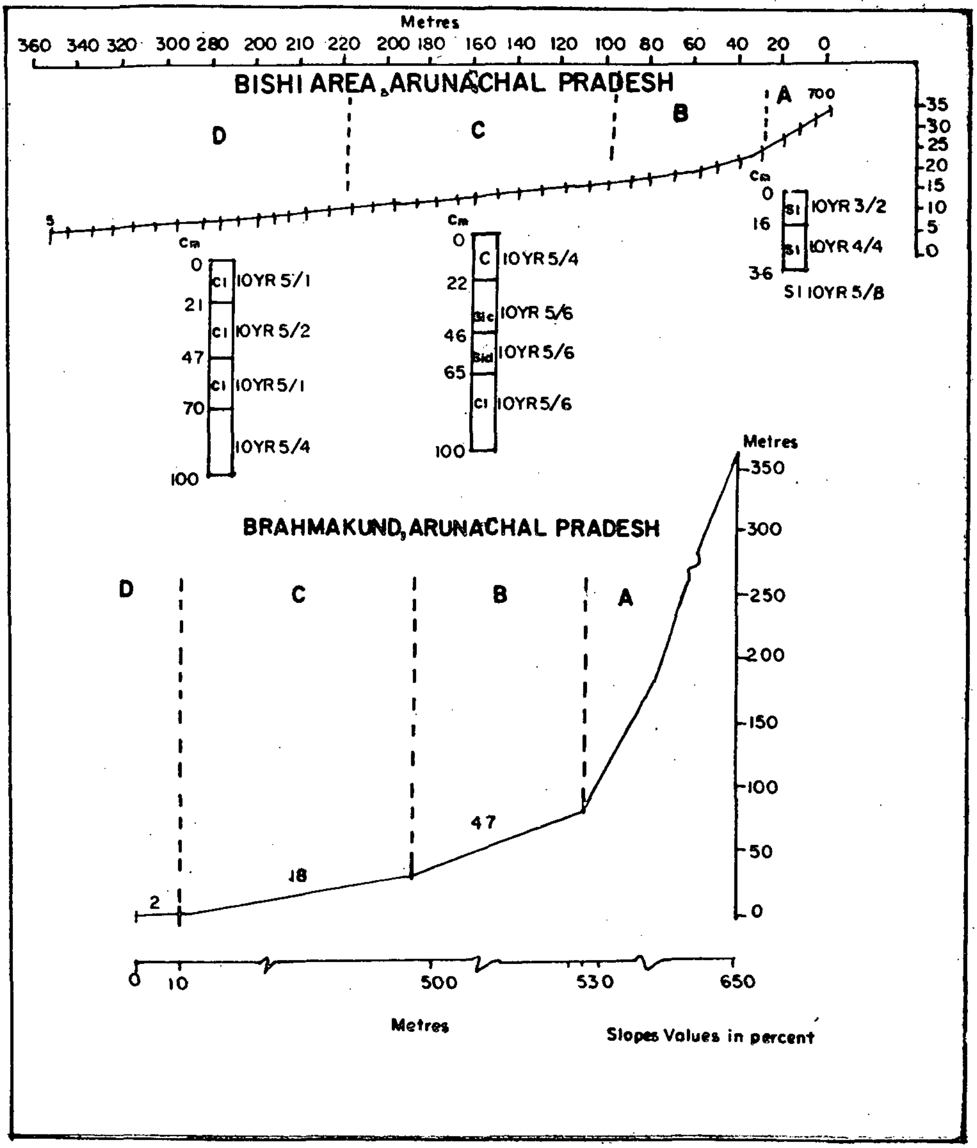

Figure 1 (i) Measured slope profiles and soils, Bishi and Brahmakund

Kareh-Brahmakund area

A typical slope profile here (Figure 1(i)) consists of a series of near-planar sites separated by pronounced angular discontinuities. The highest site A has a gradient in excess of 100% and is almost 300 m in length. Downslope in site B the gradient is 47% for 30 m, and then in site C about 18% for 500 m. The basal site D, 2%, is of variable width but only 10 m across here. Rainfall is also very high, comparable to Tezu station mentioned above. The geology is mainly granite gneiss with some schist and patches of sandstone. Topples, landslides and flows are widespread on the steep slopes. Together with slope wash processes these mass movements transport large amounts of rock debris and soil weathering deposits down into the valley floors and river beds.

During the great earthquake in 1958, associated mass movements and increased erosion by slope wash and fluvial transport resulted in heavy siltation in the valley floors (Goswami 1960). Frequent tectonic movements have produced deformations of the underlying rocks, together with increased relief amplitude, vigorous fluvial down-cutting, steeper slope angles and, hence, much slope instability. Slopes mainly consist of coarse rock debris interspersed with patches of soil.

Mon area

This district, in the northern part of Nagaland, consists of a narrow strip of hilly country along the northern margin of the Assam plains. Rainfall is about 3000 mm at Mon. Slope forms are complex and varied, characterised by diverse mass movements - ranging from rock falls and landslides to soil creep - acting in combination with slope wash and fluvial processes.

In the Yating area (Figure 1(ii)), site analysis of a typical tributary valley revealed a near-planar site mostly 95-98% and over 50 m long underlain by weathered shales. The slopes are strewn with rock debris and covered with moderately dense forest. The rainfall displaces air in the fissile shales, increasing pore water pressure and decreasing frictional resistance. Moreover, reduction of capillary pressure (associated with swelling) causes differential volume changes on fissured clay and some shales resulting in decreased cohesion. The result is extensive mass movements, including much soil creep as well as slides and flows. The soils are moderately deep, well drained, dark greyish brown, silty clay loams at the surface underlain by gravelly, brown silty loam.

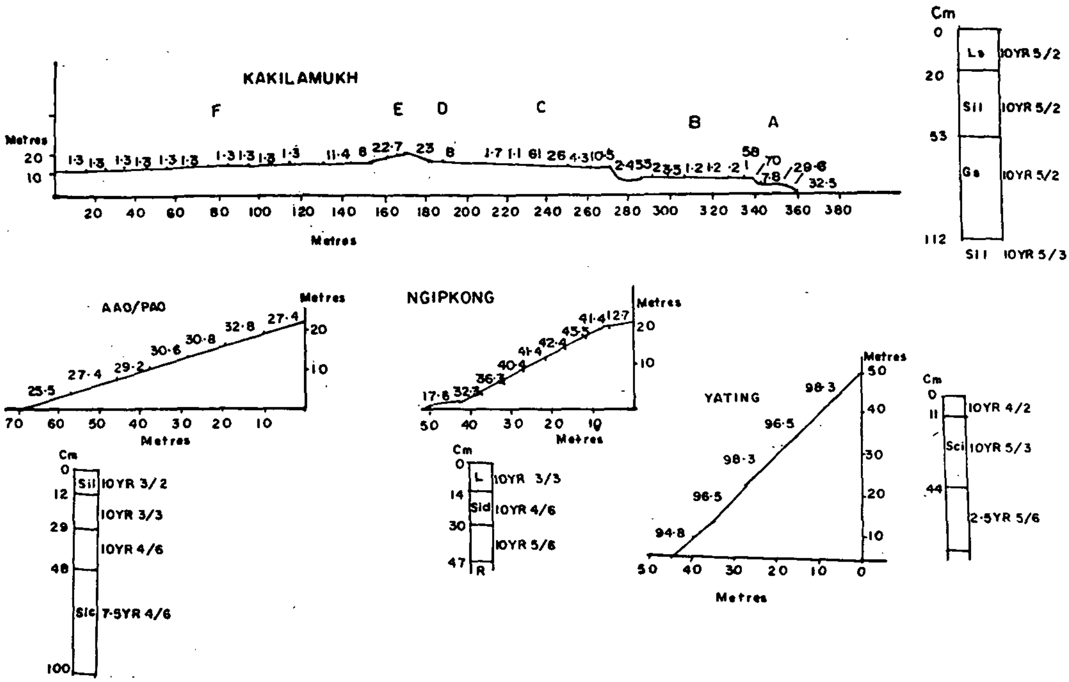

Figure 1(ii) Measured slopes and soils, Mon area

Other localities examined in this area are under 'Jhum' cultivation (also known as 'fire farming' or 'slash and burn' agriculture) which involves cutting the forest and undergrowth to ground level in December - January, waiting for the vegetation to dry and, finally, burning it to clear the land for dibbling of seeds before the onset of the rains. After a season or two, the area is abandoned in favour of a new locality. Shifting cultivation, slope instability and soil erosion has increased (ICAR 1978) with greatly increased floods in the lower sectors of the main rivers - the Brahmaputra and Barak - causing enormous losses of cultivated land every year.

In the Aao Pao area, a gently convexo-concave site was identified as a typical recurring type of the area (Figure 1ii). The measured site is 70 m long with a gradient of 27-30%, but other sites of this type can be more extensive. The base of the slope is terminated by a road cut 10 m high, over which much soil sediment deposited by runoff reflects the prevailing erosion. The soils themselves are deep, somewhat excessively drained, very dark greyish brown, silty loam underlain by dark brown to strong brown, silty loam to silty clay subsoils.

Another typical site type of the Mon district was measured at Ngipkong. It is also convexo-concave, mostly 38-42%, and is cultivated under tea and bamboo The soil is shallow, loamy at the surface, grading into silty clay below, and has a 35% cover of rock debris. The main slope processes on both of these convexo-concavo site types are creep and surface wash, erosion being greater on the steeper type - hence its shallower soil.

Kakilamukh area

This area close to the banks of the Brahmaputra consists of recent alluvium brought down by the main river and its tributary the Bhogdai. It is a zone of active flooding. When the discharge level of the Brahmaputra rises simultaneously with that of the Bhogdai the mouth of the tributary becomes choked and the obstructed waters of the Bhogdai spread laterally within their basin. Many of the mass movements in this zone are subaqueous flow slides (as defined by Hutchinson 1968). Vigorous erosion, an important factor influencing mass movements, is not typical in subaqueous situations where deposition predominates and relief is subdued. Under such conditions there occur masses of cohesionless or slightly cohesive silts or fine sands with a metastable structure. Subsequent slight disturbances may be sufficient to cause collapse of this structure which can lead, through the generation of transient high pore water pressure, to a flow slide. This phenomenon is common in the Kenduguri area.

Site analysis identified the following sites (Figure 1ii Kakilamukh). Site A is a flood bank, 18 m above the river in winter but submerged in summer, formed in a youthful sandy deposit. Site B is a more extensive, gently rounded, higher alluvial bank, 50 m wide, inclined at about 1% but with restricted flank slopes of 2-4%. At its inner margin is a distributary channel 12 m wide and 2 m deep. There is then the marginal slope of the main flood-plain itself, consisting of a degraded, irregular flank site C inclined mainly at 3-6%, but locally steepened along the adjoining distributary channel, and a slightly higher level site D, about 1-2%. A dike (E) has been constructed along the inner edge of site D in an attempt to contain all but the highest flood waters. Beyond that is an extensive, gently inclined levee - site F (1-3%) which is widespread and recurring throughout the floodplain. This levee site type, cultivated for paddy, is very common along the river Brahmaputra. Its soils are deep, well drained, greyish-brown loamy sand topsoil with greyish brown to brown silt loam to loamy fine sand subsoil.

The construction of flood-control embankments has induced rapid silting up of the river bed, so some areas behind the embankments have become swamps due to the resulting higher water table, or have been rendered useless because of siltation following occasional breaches of the embankments.

Chanki area

In the Chanki area, landslides cause much destruction of roads most years. Bedrock here consists of sandstone alternating with shales having several thick seams of coal. Site analysis was carried out on two typical but contrasting hillsides. That shown in Figure 1(iii(a))

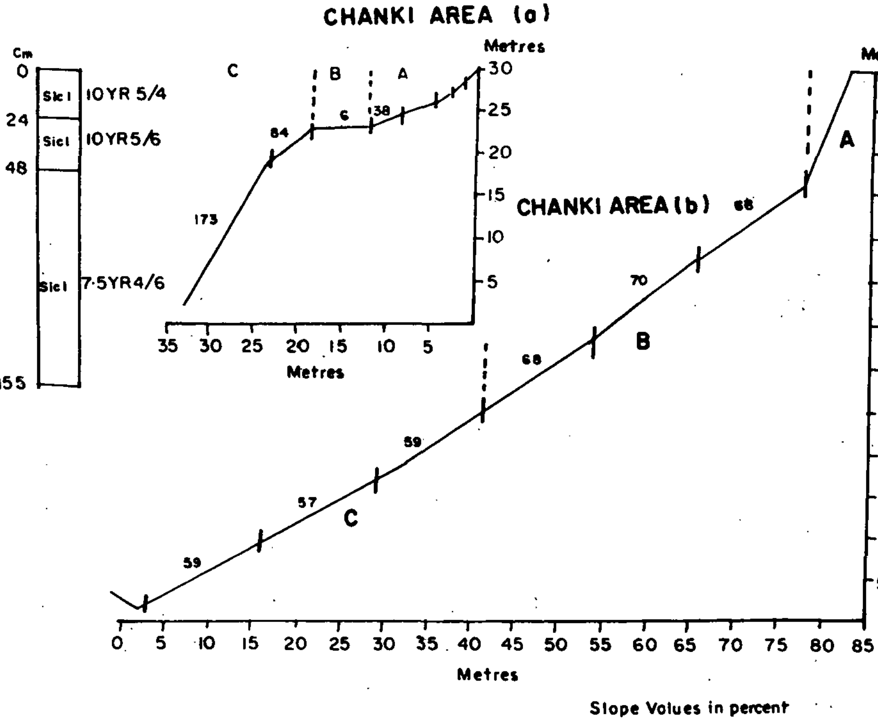

Figure 1 (iii) Measured slopes and soils, Chanki area

consists of an extremely irregular slope. In its higher part there are two distinct but localised slope segments inclined at more than 90% and 39%, respectively, which are combined as local irregularities within one site (A) because of their extremely restricted extent. At their base is a narrow road immediately downslope from which is another restricted slope segment, inclined at 84%. This latter is also delimited as a local irregularity within the steep, planar site - gradient 173% - which extends downslope. The higher, composite site A includes small terracettes expressive of creep, together with numerous erosional rills. The more extensive and typical site C - with shallow silty clay soil - is characterised by landsliding, because rainwater readily percolates into the underlying shales. This steep, erosional site type tends to occur on the lower parts of valleysides, being associated with river undercutting at its base.

A second locality was examined near Chanki village where slopes - and roads - are prone to collapse from mass movements due to a combination of steep gradients, high rainfall (about 2000 mm at Mokokchung station) and digging for coal. Site analysis on a typical valleyside identified three distinct geomorphological sites as shown in Figure 1iii(b): an upper slope 'A' consisting of a rock face 15 m high; a near-planar midslope 'B' inclined at 68-70%; and a near-planar lower slope 'C' at 57-59%. Such steep upper slopes have frequent rockfalls, consequently the middle and lower slopes are strewn with boulders. Sites B and C are subject to slides and rock flows due to a combination of circumstances. Tunnelling for coal has weakened the support of the slope both by reducing the shear resistance and by causing internal collapse. Frequent saturation of slope materials by heavy rain decreases cohesion and also increases shearing stress. The more-weathered matrix of the talus and colluvial materials is associated with spontaneous liquification when saturated. The area is also subject to earthquakes.

The soils of the sites B and C are deep, excessively drained, dark yellowish brown, sandy loam at the surface, underlain by yellowish brown, sandy loam to clay loam. They are more stony and interspersed with more debris patches in site B than in C.

CONCLUSIONS

Local soil variations are closely related to geomorphological site differences because such differences have associated changes in parent material, micro-climates, slope-forming processes and soils. Mass movements are a major group of slope-forming processes that are widespread in the study area, each occurring, individually or in combination with others, in particular geomorphological situations. The field examples presented here illustrate such relationships.

This paper draws attention to a potentially important field of study: the investigation of soil variations in relation to their geomorphological sites and natural process systems. Such investigations could be of considerable practical value because knowledge of slope forming processes would help to provide greater understanding of associated soil variations and would facilitate the relatively speedy mapping of soils in terms of their geomorphological relationships by air photo interpretation.

REFERENCES

Barthakur, M. 1978. The Brahmaputra, a myth, a gift, a source of sorrow. *Assam Science Society Mid-term Symposium on Harnessing the River Brahmaputra*, Guwahati, India.

Carson, M.A. 1976. Mass-wasting, slope development and climate. In E. Derbyshire (ed.), *Geomorphology and Climate*. Wiley, Chichester, U.K.

Chorley, R.J., Schumm, S.A. and Sugden, D.E. 1984. *Geomorphology*. Methuen, London, U.K.

Finlayson, B. and Statham, I. 1980. *Hillslope Analysis.* Butterworth, London, U.K.

Goswami, D.D. 1960. *Geology of Assam.* Guwahati University Publication, Guwahati, India

Gregory, K.J. and Walling, D.E. 1987. *Human Activity and Environmental Processes.* Wiley, London, U.K.

Hutchinson, J.N. 1968. Mass movement. In R.W. Fairbridge (ed.),

The Encyclopaedia of Geomorphology. Reinhold, New York, U.S.A.
Johnson, R.H. and Wathal, S. 1979. The Longendale landslides. *Geol. J.* 14:135-158.

Terzaghi, K. 1950. Mechanism of landslides. In *Application of Geology to Engineering Practice.* Berkey Volume, Geological Society of America.

Varnes, D.J. 1978. Slope movement types and processes. In R.G. Schuster and R.J. Krizek (eds.), *Landslides, Analysis and Control.* National Academy of Sciences, Special Report 176, Washington D.C., U.S.A.

Wright, R.L. 1972. Some perspectives in environmental research in developing countries. *Geoforum* 10:15-33.

Wright, R.L. 1973. An examination of the value of site analysis in field studies in tropical Australia. *Zeitschrift fur Geomorphologie* 17:156-184.

Wright, R.L. 1984. Applied geomorphology: In C.W. Finkl (ed.), The *Encyclopaedia of Applied Geology.* Van Nostrand Reinhold, New York, U.S.A.

AN EXAMPLE OF GEOMORPHOLOGICAL SITE-ANALYSIS IN PART OF SOUTHEAST SPAIN

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INTRODUCTION

This paper outlines a case study in which geomorphological site-analysis was applied to provide a framework suitable in the investigation and mapping of land resources, such as soils, and in land evaluation projects for development planning. Such analysis involves the differentiation of geomorphological "sites" which are small slope units of uniform shape internally, and delimited by relative discontinuities externally (Wright, this workshop). On this basis, taxonomic groups of closely similar sites - "site types" - can be identified. Members of a few, typical site types tend to recur within particular localities, so spatial groupings of sites can be delimited - "site assemblages" (which can be classified into "land complexes") - each dominated by members of one site type or of two or more closely interspersed types.

METHOD

Study area

The case study was carried out in part of Murcia province, southeast Spain, latitude 37°59′N and longitude 1°16′W. The climate is semi-arid with the hot, dry summers and cool, moist winters of the Mediterranean regime. Annual rainfall is extremely variable, 100-400 mm. The area forms part of a dissected valley plain underlain mainly by relatively uniform marl but with some interbedded conglomerate and sandstone. Air photos at a 1:20 000 scale with some enlargements at a 1:6 000 scale were used together with 1:50 000 scale toposheets. The methodology is described more fully by Wright elsewhere in these proceedings. A brief summary is given below.

Pre-fieldwork stage

The airphotos were examined stereoscopically in detail to identify, and interpret the ground relationships of, their constituent "tonal elements" - the smallest areas which could be recognised as having uniform airphoto tones.

Airphoto patterns, characterised by repetition of similar tonal elements, were then differentiated and interpreted. It was recognised that each tonal element would be associated with one or more geomorphological sites on the ground; the airphoto patterns identified would consequently represent a specific combination of sites.

A network of field sampling localities was planned to cover the range of tonal elements in the main airphoto patterns, with special reference to those elements which were most extensive or most frequently recurring.

Fieldwork stage

On reaching a sampling locality, the tonal elements previously identified on the airphoto were re-examined in terms of their ground relationships. A point was then selected in the centre of a patch of ground which appeared to be sufficiently uniform in surface form, surficial material and vegetation as to probably fall within one geomorphological site.

This point was marked on the airphoto and a detailed slope profile was measured passing through it (Figure 1). Survey stations were positioned using ranging poles at 5 m intervals, aligned in the direction of true slope at right angles to the contour, so as to transect the tonal elements of the sampling locality.

Gradient was measured between survey stations using a Suunto clinometer. Micro-relief was recorded between stations (dimensions and spacing of hummocks, terracettes, rills etc.), together with surficial materials, as described by Wright (1973), in terms of the character and occurrence of finely-divided materials, coarser rock fragments and bedrock exposures. Slope aspect was measured using a prismatic compass.

Geomorphological sites were identified as slope segments which were near-planar or regularly curved, whose boundaries were relative discontinuities in gradient (for planar sites) or rate of change of gradient (for curved sites). The minimum size of sites to be delimited was 15 m, slope segments less than this being regarded as local irregularities within sites.

The characteristic gradients for individual sites were computed as those of the centrally-placed measured lengths. Curvatures were calculated as degrees of change per metre, measured over 10 m intervals, concave curvatures having a negative sign and convex curvatures a positive sign. Soil characteristics and depth to bedrock were recorded at the centre of each site.

The sites recognised in each sampling locality, and their corresponding tonal elements, were marked precisely on the airphotos. Throughout fieldwork, emphasis was placed upon establishing and interpreting such relationships between site characteristics and the associated airphoto tonal elements.

After comparative evaluations of the individual geomorphological sites in all the sampling localities, site types were identified, each being a group of sites that were closely similar in terms of form (slope gradient, curvature, position in toposequence) and composition (texture of surficial materials and depth to bedrock). On this basis site assemblages were delimited as areas dominated by members of one site type or of two or more closely interspersed types.

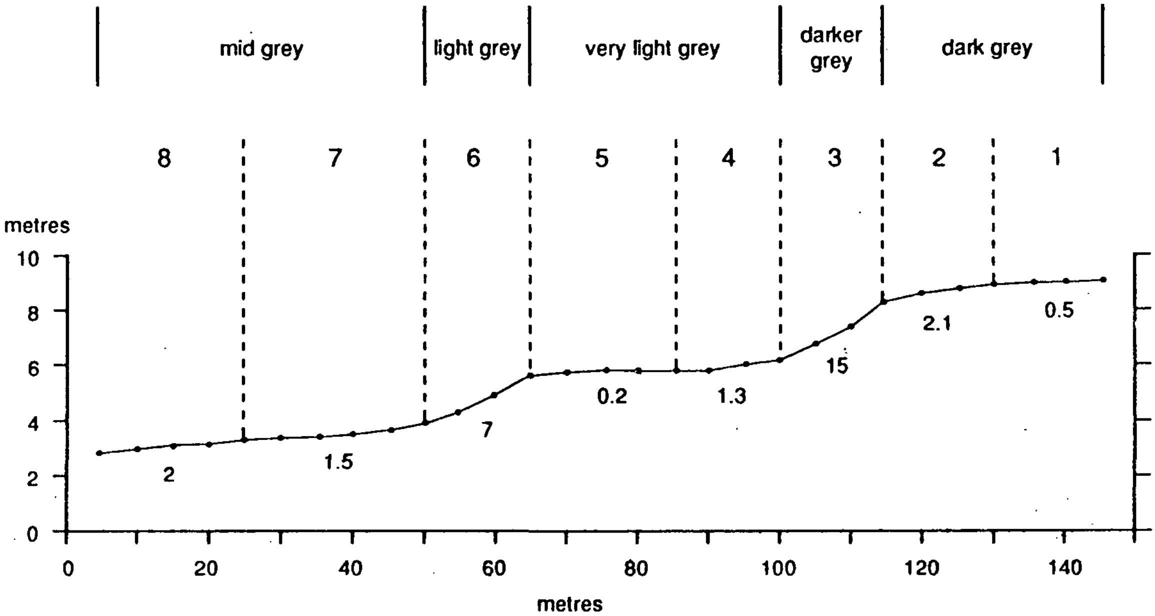
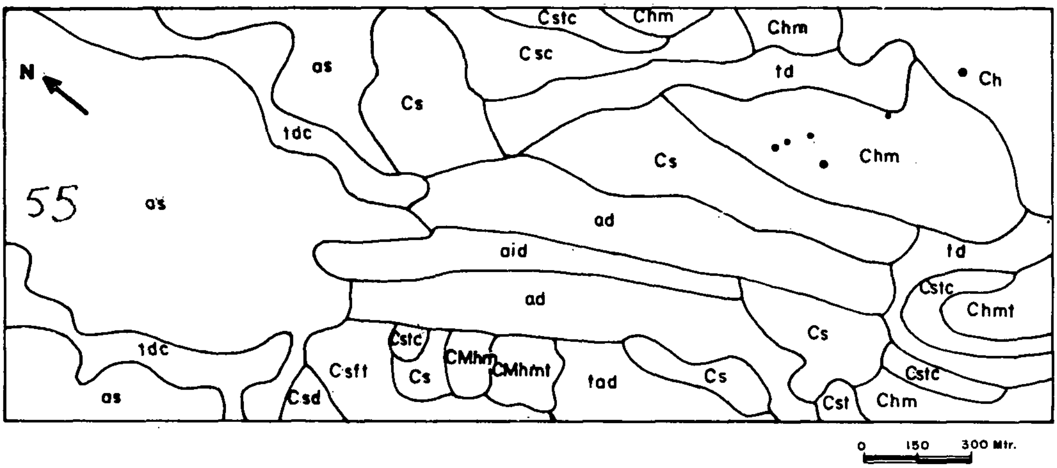


Fig. 1 Measured slope profile delimiting eight sites, 1-8, with central gradient values in degrees (vertical exaggeration x 2.5). Dots indicate survey stations. Underlying bedrock is marl. The corresponding tonal elements are shown above the profile.

Slope forms and surficial materials are as follows, the numbers in brackets representing slope curvature in degrees of change per metre (positive signs convex, negative signs concave); the numbers not in brackets representing slope gradients.

Site 1:	interfluve crest near-planar (+0.08) 0.5 - 1°	clay loam occasional pebbles/cobbles
Site 2:	crest margin near-planar (+0.1) 1 - 2.1°	silty clay loam to silty clay scattered pebbles/cobbles
Site 3:	sub-crestal slope concave (- 0.46) 5.8 - 15°	silty clay to silty clay loam moderately dense gravel
Site 4:	inner margin of midslope bench near-planar (- 0.03) 1.3 - 2.4°	silty clay
Site 5:	outer margin of midslope bench near-planar (+ 0.02) 0.1 - 0.3°	silty clay with marl near the surface
Site 6:	bench flank-slope concave (- 0.34) 4.7 - 8.1°	silty clay loam to clay loam
Site 7:	interfluve lower slope near-planar (-0.17) 0.8 - 2.5°	silty clay
Site 8:	drainage floor margin near-planar (-0.07) 1.9 - 2.7°	silty clay over loam

Assemblages characterised by the same dominant sites types were then mapped as land complexes, the mapping being concentrated initially in and around sampling localities and then extended across intervening areas along cross-country traverses, aided by extrapolation of sampling data on the basis of airphoto interpretation of their tonal-element associations. Precise verification of the airphoto relationships of land complex boundaries was facilitated by mapping key areas on airphoto enlargements at a scale of 1:6 000.



LEGEND

Ch	:	Higher hills
Chm	:	Lower hills
Chmt	:	As above but with cultivation terraces
CMhm	:	Lower hills predominantly on marl
CMhmt	:	As above but with cultivation terraces
Cs	:	Hill spurs in tributary valleys
Csc	:	Spurs downvalley from Cs, with calcrete gravel
Cst	:	Spurs with cultivation terraces
Cstc	:	As above but with calcrete gravel
Csft	:	Upper margins of footslopes
Csd	:	As above with restricted drainage zones
as	:	Middle and lower sectors of footslopes
td	:	Entrenched upper sectors of drainage floors
ad	:	Unchannelled middle sectors of drainage floors
aid	:	Low, erosional interfluves adjoining ad
tdc	:	Entrenched lower sectors of drainage floors

Fig. 2 Land complex map of part of the study area

Post-fieldwork stage

The distinctive features of the main site types were finalised together with the land complex mapping, by extrapolation, on the basis of further airphoto interpretation, of the relationships established in sampling localities, along cross-country traverses and in key areas mapped precisely on the ground.

Detailed descriptions of the land complexes were compiled, incorporating each constituent site type in terms of geomorphology and soils (normally vegetation and land use also, but these could not be recorded in this exploratory case study). Block diagrams and other illustrative material for each land complex were produced by reference to field sketches, photographs and records on the sampling data sheets.

RESULTS AND DISCUSSION

The study area appeared deceptively simple on general inspection on the ground and on airphotos, consisting of an apparently uniform hill land, relief amplitude up to 80 m, and an adjoining, gently sloping footslope, relief amplitude mainly less than 2 m. Geomorphological site analysis revealed, however, that the area consisted of a diverse mosaic of site types within numerous distinctive site assemblages.

These latter were mapped into 20 land complexes, an extract from the mapping being shown in Figure 2. A system of symbols was employed for the mapping units: the first capital letter(s) represented bedrock geology, followed by a small letter for geomorphology, with additional symbols for soil, vegetation and land use where appropriate. Cstc, for example, represented a bedrock sequence characterised by conglomerate interbeds (C), eroded into hill spurs (s) with cultivation terraces (t) having calcrete gravels (c) on the surface.

The land complexes were given local names derived from type areas (Cabezo, for instance), and were grouped into landform types (Table 1) based on relief amplitude and dominant slope angles computed from their characteristic site types. It is not possible here to describe the individual land complexes, but a brief example can illustrate the nature of their identification and essential characteristics. The hill land for instance, consisted of a single, apparently uniform tract, with gently rounded crests and convex to concave or near-planar valleysides underlain by interbedded marl, sandstone and conglomerate. Soils were commonly shallow, medium- to coarse-textured Brown-Calcareous Sierozems (Aridisols). Site analysis identified several distinctively different land complexes, however, the two largest being Cabezo 1 and Cabezo 3.

Each of these latter was composed of a similar range of site types, but analysis of their spatial distributions identified Cabezo 1 as having two co-dominant site types forming much of its more extensive lower slopes, and Cabezo 3 with two contrasted co-dominants within its more extensive middle slopes. The differences between the two pairs of co-dominants were only apparent on measurement, but were strikingly consistent diagnostic features of the two complexes, were associated with subtle soil changes, and were ecologically important as reflected in their respective semi-natural vegetation communities (Table 2).

After this site-type differentiation it was recognised that the two complexes had other contrasted features, including different relief amplitudes, 50-80 m in Cabezo 1 and 30-50 m in Cabezo 3.

Site characteristics in such geomorphologically-defined complexes are expressive of their natural process relationships. Osman Salleh (1985), for example, found that eroding and transporting processes on these hillsides were reflected in the thickness of "colluvium" (ie. soil) and in volume of the eroded sediment within adjoining valley floors: plant cover and slope gradient accounting for more than 75% of the variance in depth of
Such environmental interrelationships of soil-sites and site assemblages illustrate the practical relevance of these entities as a framework for organising multidisciplinary researches for land evaluation and development planning, and for extrapolating the results of these researches (Wright 1972b, 1984, 1987). A major requirement for these more intensive researches is the statistical analysis of soil variability (Wright and Wilson 1979).

Data for a wide range of physical and chemical soil characteristics, and surface attributes important for agriculture, were collected using a stratified random sampling design, and analysed statistically to assess the validity of the land complex differentiation and their constituent mapping units (individual site assemblages). The analyses revealed that (a) the individual mapping units and their broader land complexes each had a high degree of internal homogeneity in terms of the measured properties; (b) there was a high degree of similarity between mapping units in the same land complex; (c) different land complexes were different pedologically in terms of many of the measured properties.

These results, indicating many close similarities between mapping units of the same land complex and many significant differences between different complexes, confirmed the validity of the site analysis procedure as a framework for, the speedy differentiation of detailed soil variations relevant in land use planning.

Landform types	Land complexes	Relief amplitude (m)	Dominant slope angles (°)
Higher hills	Cabezo 1	50 - 80	15 - 25
Lower hills	Cabezo 3	30 - 50	10 - 20
	Hermosa 1	Up to 30	15 -25
	Hermosa 3	Up to 30	15 - 20
Hill spurs	Salada 1 Salada 4 Salada 6	5 - 8	5 - 10
Footslopes	Salada 5	Up to 4	1 - 4
	Salada 7	Up to 4	1 - 4
	Palmera 2	Up to 2	1 - 2
	Palmera 3	Up to 2	1 - 2
Drainage floors	Zanja 1	Up to 2	Up to 3
	Canada 1	Up to 2	Up to 2
	Canada 2	Up to 2	Up to 2
	Canada 3	Up to 2	Up to 2
	Barrancos	Up to 8	Up to 3
Alluvial terraces	Palomares 1	Up to 8	1 - 2
	Palomares 3		5 - 10
	Palomares 4		1 - 10
	Olivas		1 - 3

Table 1. The landform types and their constituent land complexes

Dominant site types	Slopes*	Soils	Vegetation
A1 Concavo-convex lower slopes	± 0.35 11-23° up to 30m	Shallow, yellowish brown to brown sandy silt loam to sandy clay loam	Shrub and perennial grass 12-20% cover 8-14 species Dominants: *Thymelaea hirsuta* *Rosmarinus officinalis*
A2 Convex lower slopes	0.5 to 1.0 15-25° up to 30m	Shallow, light yellowish brown to pale brown Stony sandy loam to sandy silt loam	Shrub and perennial grass 11-32% cover 13-17 species Dominants: *Fumana ericoides* *Helictotrich filifolium*
B1 Steeper concave to convex midslopes	-0.34 to 0.48 15-25° up to 25m	Very shallow pale brown to dark yellowish brown stony sandy loam	Shrub 2-17% cover 7-20 species Dominants: *Thymus hyemalis* *Thymelaea hirsuta*
B2 Less steep concave to near-planar midslopes	-0.74 to 0.2 11-19° up to 20m	Shallow light yellowish brown to light grey Stony sandy clay loam	Shrub and perennial grass 7-18% cover Up to 15 species Dominants: *Thymelaea hirsuta* *Fumana thymifolia*

* The listed figures refer to:-
- slope curvature in degrees per metre (convex, positive sign; concave, negative sign)
- characteristic gradients
- slope lengths

Table 2. Dominant site-types of Cabezo 1 (A1, A2) and Cabezo 3 (B1, B2) land complexes

REFERENCES

Osman Salleh, K.B. 1985. *Drainage Basin Analysis of Erosion and Deposition in Part of Southeast Spain.* Ph.D. Thesis, University of Sheffield, U.K.

Wright, R.L. 1972b. Some perspectives in environmental planning in developing countries. *Geoforum* 10:15-33

Wright, R.L. 1973. An examination of the value of site analysis in field studies in tropical Australia. *Zeitschrift fur Geomorphologie* 17: 156-184

Wright, R.L. 1984. Applied geomorphology. In C.W. Finkl (ed.). *The Encyclopaedia of Applied Geology.* Van NostrandReinhold, New York, U.S.A.

Wright, R.L. 1987. Integration in land research for Third World development planning. *Landscape Ecology* 1:107-117

Wright, R.L., and Wilson, S.R. 1979. On the analysis of soil variability with an example from Spain. *Geoderma* 22:297-313.

CURRENT AND PROJECTED APPLICATION OF REMOTE SENSING FOR RESOURCE MAPPING AND MONITORING - A CASE STUDY FROM AFRICA

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INTRODUCTION

Remote sensing has emerged as a potent and efficient technology for mapping and monitoring natural resources. At present the National Bureau of Soil Survey and Land Use Planning is using visual interpretation of satellite images to prepare physiographic base maps for soil mapping. The potential use of satellite imagery can be greatly enhanced by digital image processing using a computer. There is a broader scientific interest in quantifying regional resources using coarse-resolution satellite data. These studies, to date, have used the Normalised Difference Vegetation Index (NDVI), or "greenness" index for the multi-temporal analysis of vegetation but other spectral measures may prove equally useful.

Regional grassland monitoring of large areas that cannot be covered by ground-based techniques, for example in the Sahel, has attracted special interest. A precise delineation of biomass is possible if the variation due to soil factor is accounted for. Multi-temporal imagery is essential since vegetation vigour and cover change from season to season. It is also useful to examine annual changes in vegetational communities, especially where the vegetation is surviving in marginal circumstances.

METHODS

In the present study, Normalised Difference Vegetation Index (NDVI) images (8km resolution) from January to December 1984 were analysed for seasonal migration of major vegetation belts and the condition of the vegetation in some critical areas of Africa.

The images of vegetation indices were derived from the Advanced Very High Resolution Radiometer (AVHRR) on board the NOAA series of polar-orbiting satellites. The NDVI was computed from the red and near infra- red (NIR) reflectance by the expression NIR-red/NIR+red. High index values are obtained for areas carrying a high per cent of vigorous, green vegetation; low values are obtained for unvegetated areas. The index is scaled from 0 to 255; values in excess of 140 represent, in broad terms, active vegetation. In order to minimise the effects of off-angle viewing, atmospheric variation and cloud contamination, maximum value compositing was undertaken. The monthly images were density sliced. The political boundaries and the grid points were overlain on the monthly images.

Eight areas selected for study: the Sahara, the Sahel of Niger, Central African Republic, the rain forest of Zaire, the Central Highlands of Angola, the deciduous bush of Tanzania and the Kalahari. The analyses pertained to (a) the rate of spatial change at the Savanna/Sahel transition, both to the north and south of equator; (b) the rate of migration of 'green wave' in different parts of the continent; and (c) behaviour of NDVI in the Sahelian area by selecting two north-south transects with four points each for predicting success or failure of crops using rainfall data.

RESULTS AND DISCUSSION

The interpretation is based on the NDVI curves produced by Townshend and Justice (1986).

The mean data values for 3 x 3 pixel for eight locations (Fig. 1) indicate that, in both January and November, values of NDVI are higher in the southern and northern Savanna zones than in the rain forest of Zaire. By December-February the northern Nigerian Savanna also had a low NDVI, probably due to senescent vegetation. There was a marked decrease in NDVI for northern Nigeria and southern Niger from August up to December. A high rate of spatial change in NDVI was observed to the north of equator during the high sun season.

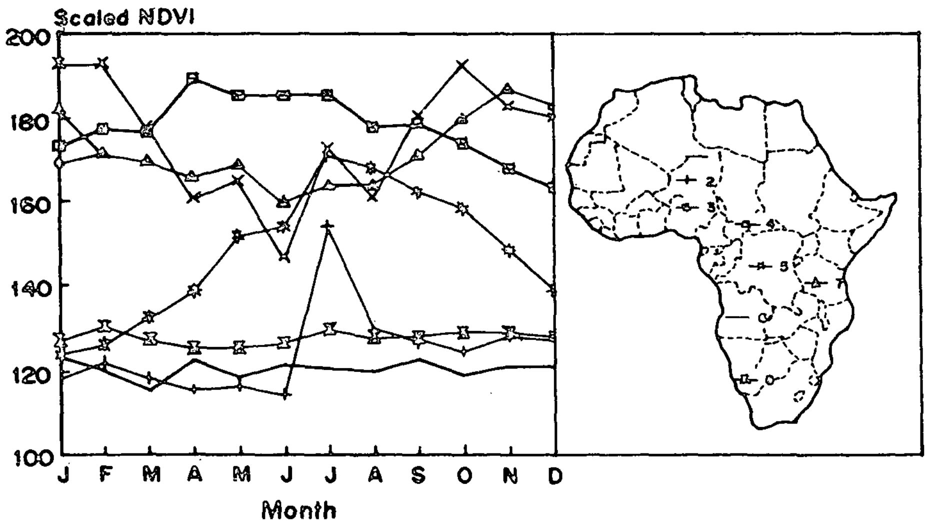

Figure 1 NDVI curves for characteristic cover types of Africa

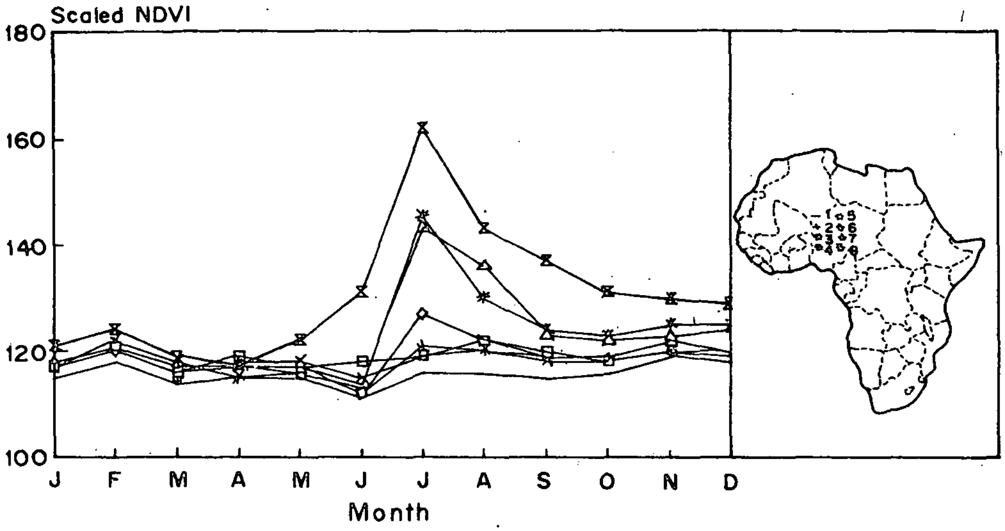

Figure 2 North-South transect of NDVI plotted against time.

From July to February marked contrasts were seen between the northern and southern areas of the continent. In the northern part, the continuous belt of high NDVI values was replaced by much lower values but over fairly restricted area. Conversely, there was a considerable southward extension of greenness into northern Botswana and Namibia associated with the onset of rains.

The Sahara and Kalahari deserts had low NDVI's throughout the year due to sparse or no vegetation cover. In contrast, the tropical rain forest areas within the Guinea-Congolean region had high NDVI's throughout the year.

In the Nigeria/Niger area, the mean annual rainfall decreases northwards and this is reflected in the vegetation. To understand the phenology of the vegetation across these precipitation gradients, the NDVI values of two north-south sample transects were plotted against time (Fig. 2). The similarity in the curves of these two transects shows increase both in peak of NDVI curve and duration of active vegetation with decrease in latitude. The two plots showed vegetation response to the north-south precipitation gradient.

CONCLUSION

This study shows the potential usefulness of the technique in monitoring forest and grasslands. Also, when one combines the spatial rapidity of the decrease in NDVI with spatial localisation of rainfall variability from mean of each year, the spatial rapidity of the decrease in NDVI with spatial localisation of rainfall variability from mean of each year, the consequence for the success of crops in any year is apparent.

Examination of temporally composited NDVI images at 8km resolution and corresponding temporal profiles has demonstrated their value for monitoring green-leaf dynamics at a continental scale.

Presently, in India, agro-climatic zoning takes into account only climatic factors and soils (Sahai and Dudhwal 1989). An index of actual vegetation cover/vigour using NOAA-AVHRR data could be a very useful additional input. The NDVI could also be used to estimate the agricultural crop area.

CURRENT AND PROJECTED USE OF SOIL SURVEYS WITH SPECIAL REFERENCE TO REMOTE SENSING - A CASE STUDY IN THE UK

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INTRODUCTION

The work of a national soil survey institution includes not only identification, classification and mapping of soils but also the interpretation of soils data for various applications. As an example of the variety of information that can be provided, a detailed soil survey was made of the Silsoe College farm, Bedfordshire, UK, and thematic maps were developed using the SPANS geographic information system.

In a separate exercise, information was used in precise discrimination of biomass objects through radiometric studies.

METHODS

The Silsoe College farm encompasses 121 ha of subdued relief. Mean annual rainfall is 584mm, and accumulated temperature above 0°C is 1443 day degrees. Soils were described using the terminology of Hodgson (1976) and classified according to Avery (1980) and Clayden and Hollis (1984). The 1:10 000 soil map was digitised using SPANS and thematic maps for workability, suitability for winter wheat, and slurry acceptance potential were generated.

Spectral reflectance for soils and biomass was studied using a TM VNIR radiometer which records information in bands 1 (0.45-0.52µm), 2 (0.52-0.60µm), 3 (0.63-0.69µm) and 4 (0.76-0.90µm) of the Landsat Thematic Mapper. Normalised difference vegetative index (NDVI) was calculated using the formula, NDVI = TM4-TM3/TM4+TM3.

RESULTS AND DISCUSSION

Twelve soil series were identified and mapped (Fig. 1A). Brown and reddish brown, coarse-textured soils derived from Lower Cretaceous greensands are classified as typical brown sands (Cottenham Series), typical brown earths (Bearsted, Rivington) and typical argillic brown earths (Maplestead, Ludford). Clayey glacial till containing chalk has given rise to typical calcareous pelosols (Hanslope) and typical argillic pelosols (Faulkbourne). Pelostagnogleys (Denchworth) and typical calcareous pelosols (Drayton and Evesham) are derived from Ampthill and Oxford clay. Holdenby and Lawford series are prominently mottled, non-calcareous clays.

Interpretations of the soil map based on parameters which influence the management of land, such as workability, crop suitability, and slurry acceptance potential have been undertaken (Fig. 1 B, C, D).

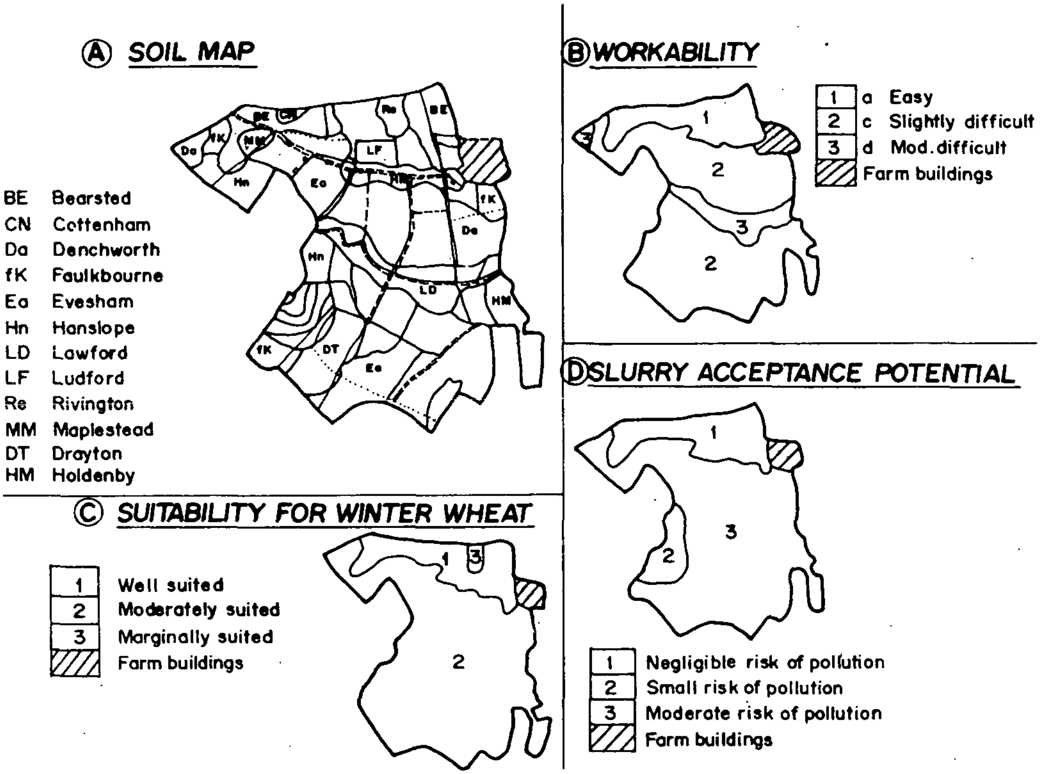

Figure 1 Soils and interpretative maps of Silsoe College Farm

Workability

The moisture content strongly affects the bearing strength of the topsoil. The soil factors considered in assessing workability relate to the ability of the soils to retain or dispose of water. Duration of waterlogging, the clay content and field capacity are used to produce a workability rating. By integrating the climate and soil data, the average number of machinery work days for each soil series is estimated (Thomasson 1982). The rating for soils at Silsoe ranged from easy to moderately difficult workability (Fig. 1B).

Suitability for Winter Wheat

Empirical suitability assessments are based on the interactions between soil and climate (Hodge et al 1984). The number of machinery work days, defined as the days when the soil is drier than field capacity, is an estimate of the time available to cultivate the land to sow and harvest the crop in good conditions. Degree of droughtiness, assessed from crop-available water stored in the soil, crop rooting and potential soil moisture deficit, is used as a measure of the ability of the soils to supply sufficient water for optimum crop growth. Again, this judgement needs good meteorological data for the area and good soil physical data, both of which have been gathered by the Soil Survey of England and Wales over many years. The soils of the College farm were judged to be well-to marginally suited to wheat (Figure 1 C).

Suitability for Slurry Acceptance

Slurry contains elements valuable for plant growth. However, to accept large quantities of slurry without environmental damage, the soil must be permeable and deep enough for infiltration but must contain sufficient clay minerals, organic matter and bases to allow bacterial and chemical action to render potential pollutants ineffective. Permeability, wetness, particle-size, slope, and depth to bedrock are considered to predict the suitability of a soil for slurry application. The farm soils had negligible to moderate risk of pollution. (Figure 1 D).

Radiometric Studies for Delineation of Agricultural Crops

Radiometric studies of plants and soils were carried out to establish correlation between objects, spectral reflectance, and NDVI. Once the indices are correlated with different soils and crops, fast and accurate delineation of crops is possible through digital mapping. Several workers (Sridhar et al 1988; and Potdar et al 1987) have delineated crops, but the spectral reflectance of soils has not been included in these studies. The reflectance values in the four bands for bushes, lawn, grass, pasture, and emergent wheat (Table 1) showed stronger reflectance in the NIR band than in other bands. The wheat stubble and bare soil did not vary much in reflectance between the bands, and curves were in straight line. The curves were also straight for all biomass objects in bands 1, 2 and 3 but suddenly shot up in NIR band (Fig. 2A, 2B). Chlorophyll in leaves absorbs light most strongly in bands 1, 2 and 3 but light is reflected in NIR band resulting in a stronger reflectance.

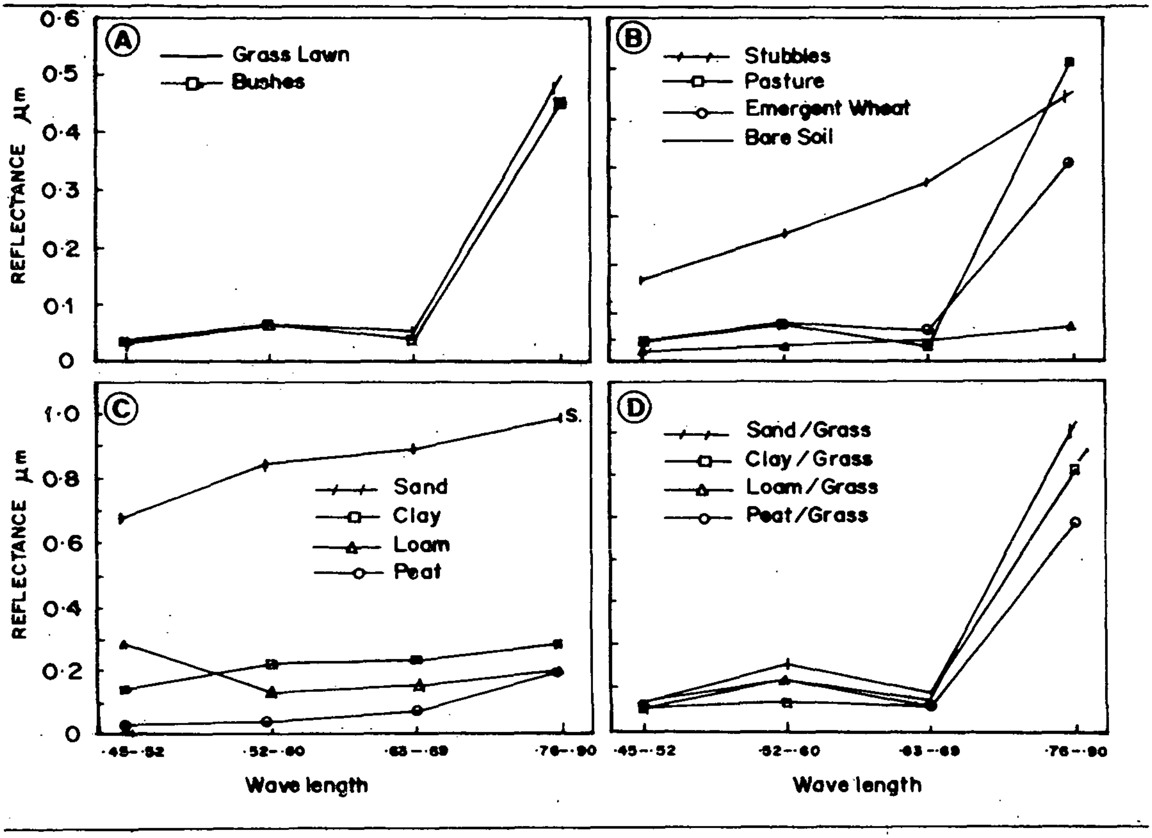

Figure 2 Reflectance patterns of soils and different vegetation types

Comparing the variable soils under constant biomass, reflectance was observed for dry clay, loam, sand and peat samples with or without covering grass (Table 1). The sand showed highest reflectance whereas peat had lowest, and vice-versa for NDVI (Fig. 2C). Even though the grass cuttings were spread over all the samples, the difference in reflectance could be measured, indicating a strong influence of soils on spectral reflectance (Fig. 2C and D).

Table 1. Spectral reflectance of soils and different vegetation type

Target	Reflectance (albedo) in different bands				NDVI
	1	2	3	4	
Bushes	0.035	0.066	0.039	0.656	0.887
Grass lawn	0.031	0.063	0.055	0.502	0.800
Pasture	0.042	0.075	0.034	0.623	0.890
Stubble	0.169	0.262	0.368	0.545	0.193
Emergent wheat	0.044	0.080	0.060	0.412	0.740
Bare soil	0.020	0.030	0.040	0.047	0.250
Peat	0.035	0.039	0.069	0.190	0.565
Loam	0.289	0.129	0.152	0.190	0.220
Clay	0.144	0.215	0.229	0.280	0.238
Sand	0.675	0.844	0.888	0.985	0.143
Peat/Grass	0.048	0.058	0.047	0.472	0.832
Loam/Grass	0.062	0.112	0.047	0.472	0.846
Clay/Grass	0.058	0.152	0.078	0.603	0.840
Sand/Grass	0.055	0.114	0.060	0.709	0.863

The spectral reflectance of soils and biomass was highest for sand and lowest for peat. The bushes reflected highest and emergent wheat lowest in NIR band. Variation in spectral reflectance values when soil was constant is attributed to variation in chlorophyll content in different objects of biomass. Differential response of soils is attributed to variation in soil texture, moisture and organic matter content. A crop may show different spectral reflectance on different soils behaviour. So a better delineation is possible through the study of spectral reflectance of both soils and biomass.

REFERENCES

Avery, B.W. 1980. *Soil classification for England and Wales. (Higher categories)*. Soil Surv. Tech. Monogr. 14, Soil Survey of England and Wales, Rothamsted Experimental Station, Harpenden, U.K.

Clayden, B. and Hollis, J.M. 1984. *Criteria for differentiating soil series*. Soil Surv. Tech. Monogr. 17, Soil Survey of England and Wales, Rothamsted Experimental Station, Harpenden, U.K.

Hodge, C.A.H., Burton, R.G.O., Corbett, W.M., Evans, R. and

Seale, R.S. 1984. *Soils and their use in Eastern England.* Bull. 13 Soil Survey of England and Wales, Rothamsted Experimental Station, Harpenden, U.K.

Hodgson, J.M. (Ed.) 1976. *Soil survey field handbook.* Soil Surv. Tech. Monogr. 5, Soil Survey of England and Wales, Rothamsted Experimental Station, Harpenden, U.K.

Potdar, M.B., Kalubarme, M.H., Sharma, R., Biswas, B.C. and Dubey, R.C. 1987. Hectarage estimation of 1985 sorghum in Solapur district using Landsat MSS data. Scientific note 7, Space Application Centre, Ahmedabad, India

Sridhar, V.N., Mahey, S.S., Pokharna, S.S., Cheema, S.S., Jhorar, O.P. adn Sidhu, S.S. 1988. Estimation of wheat area in Punjab using single date Landsat MSS data. Proc. Nat. Symp. Remote Sensing in Rural Development, HAU, Hissar, India

Thomasson, A.J. 1982. Soils and climatic aspects of workability and trafficability. *Proc. 9th Conf. Int. Soil. Tillage Research Organisation,* Osijek, Yugoslavia, 551-7

APPLICATIONS OF REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEMS IN SOIL DEGRADATION ASSESSMENT

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INTRODUCTION

The 1:250 000 soil maps being prepared by National Bureau of Soil Survey and Land Use Planning can be interpreted for various themes, including land degradation (Sehgal et al 1990). Manual interpretation and cartography take enormous time which, however, can be reduced by the use of Geographic Information Systems (GIS). Burrough (1986) described GIS as a set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world for a particular purpose.

The value of remote sensing techniques in soil degradation studies can be enhanced by integrating vector-based soil map data with raster data from satellites. In particular, superimposition of a leaf area index (LAI) map over a soil map may help in assessing and monitoring soil degradation.

The study area, part of the Indo-Gangetic alluvial plain of Uttar Pradesh, extends from 20° to 30°N latitude and 77°45′ to 78°15′E longitude, with elevation ranging from 205 to 270m above mean sea level. The climate is sub-humid tropical. The mean annual maximum and minimum temperatures at Roorkee are 30.2°C and 17.0°C, respectively. The average annual rainfall is 1164mm.

MANIPULATION OF DATA

The study area was located on the Landsat image of band 7 and its location (start and end of scan line and pixel) was noted. Details of Landsat data used for the study area are given in Table 1.

Table 1. Details of satellite data

Season	Date	Scene id	Sun Angle	Sun Azimuth	Image Rating
Dry	14 Nov 72	1144-04512	36°	150°	8888*
Cool	2 Dec 72	1132-04512	32°	151°	8888
Moist Cool	12 Feb 73	1204-04512	36°	139°	8882

* Refers to quality rating of bands 4, 5, 6 and 7 respectively; range 0-9 with 9 being the best.

The images were rectified for atmospheric and geometric correction by the. DIPEX system. The Leaf area index (LAI) for imagery of above three dates was processed using following function:

Leaf area index F = SqRT (F) (1) - F (2)/F(1)+F(2)+1.0
where, F(1) is MSS band 7 and F(2) is MSS band 5

After performing these exercises, the data were transferred to a floppy using the ERDAS image processing system for image analysis on the ILWIS GIS (Valenzuela 1988). The LAI generated on DIPEX were processed and LAI for three dates were registered and then a multi-temporal LAI of February, December and November in red, green and blue respectively, was generated. The colours were identified using ISCC-NBS centroid colour chips. The physiography and soil map of the upper Ganges plain was digitised.

RESULTS AND DISCUSSION

The multi-temporal LAI showed wide variation in colours (represented only in monochrome Fig. 1). Water bodies and rivers are depicted by strong purplish blue (196 S.pB) and deep purplish blue (197 deep pB). A large area is depicted by strong green (141 SG), very dark greenish blue (175 v d gB) and black (267 Black) colours indicating the area covered by rainy season crops. The southwest and central portion near the Ganges, depicted by mosaic of light orange-white colour, indicated the presence of dominantly winter crops; the centre of image, depicted by greenish-white (153 g white) colour, the presence of vegetation from November to February; and in the northeast portion, a patch depicted by strong brown (55 s Br), showed the presence of luxurious vegetation in the month of February. A linear feature parallel to the river Solani, represented by black (267 Black) colour, was due to the presence of very sparse or no vegetation throughout the seasons.

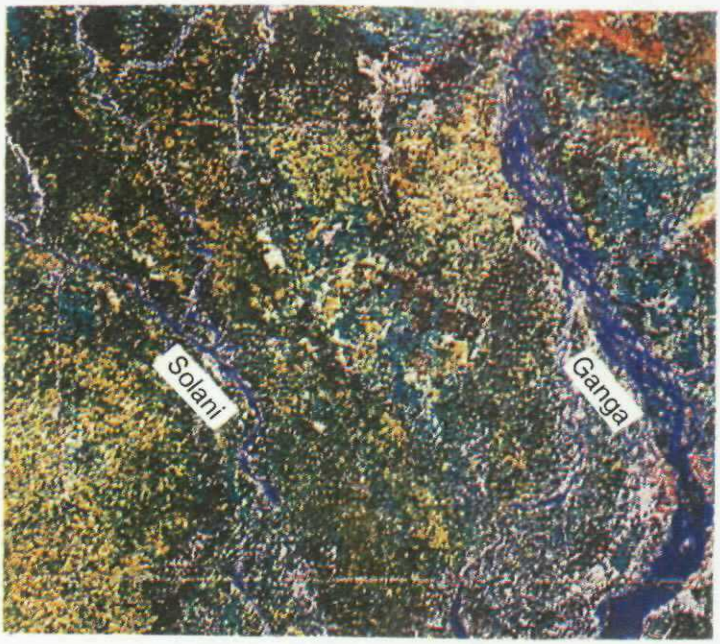

Figure 1 Multi-temporal LAI of the upper Ganges Plain

The physiography map (Figure 2) prepared from the satellite image was digitised and transformed into a raster base. Information about each polygon has been listed in the tabular data base (Table 2). The thematic map of degraded soils (Figure 3) was generated from the digitised map and soil-site characteristics recorded in Table 2. Three types of soil degradation mapped were (i) soils with shallow to moderately shallow watertable; (ii) severely-eroded soils, and (iii) salt-affected soils with moderately shallow watertable.

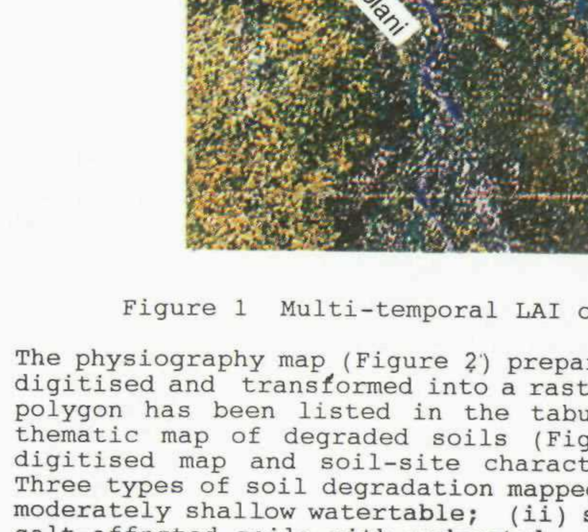

Figure 2 **Physiography of** the upper Ganges Plain

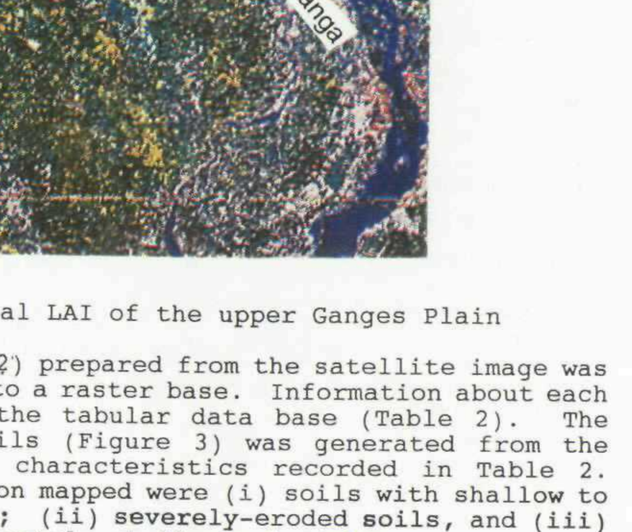

Figure 3 Degraded soils in the upper Ganges Plain

Table 2. Physiography, soils and site characteristics of the upper Ganges plain

Physiography and map symbol	Slope	Drainage	Ground Water	Erosion	Particle size class	Land Use	Soils
1	2	3	4	5	6	7	8
a) Ganges alluvial plain							
Old braided river plain(1)	2	4	3	2	2	irrigated	Ochrepts Fluvents
Young braided river plain(2)	1	4	4	2	2	irrigated	Orthents Fluvents
Recent deposits(3)	1	3	2	2	1	op-forest	Fluvents Aquents
b) Solani alluvial Plain							
1) Upper alluvial plain							
Channels(4)	1	3	3	2	3	irrigated	Aqualfs
Dunes & levees(5)	2	7	5	2	1	rainfed	Psamments
Dissected fringe(6)	3	7	5	3	1	op-forest	Psamments
Channels halomorphic(7)	1	3	3	2	5	irrigated	Ochrepts Natrustalfs
Plain(8)	1	5	5	2	5	irrigated	Ochrepts Aqualfs
2) Lower alluvial plain (9)	1	3	3	1	5	irrigated	Fluvents Aquepts
c) Piedmont plain(10)	2	5	4	2	2	rainfed arable	Orthents Fluvents
d) Tarai(11)	1	3	2	1	3	irrigate and forest	Aquepts Udolls

KEY:

Slope: 1=0-1%, 2=1-3%, 3=3-8%
Drainage: 3=imperfect, 4=moderately well, 5=well, 7=excessive
Groundwater (depth from surface): 2=50-100cm, 3=100-200cm, 4=200-400cm, 5=>400cm
Erosion: 1=none to slight, 2=moderate, 3=severe
Particle size class: 1=sandy, 2=coarse loamy, 3=fine loamy, 5=coarse loamy to fine loamy

CONCLUSIONS

The superimposition of temporal LAI data on soil and physiography map can help in assessing the potentiality of the soil. The study indicated that temporal leaf area index enables the determination of areas with lower biomass index, indicating degradation of soils.

REFERENCES

Burrough, P.A. 1986. Principles of Geographic Information System for Land Resources Assessment. Clarendon Press, Oxford, UK.

Sehgal, J.L., Saxena, R.K. and Pofali, R.M. 1990. Degraded soils - their mapping through soil surveys. In Technologies for Wasteland Development, I.P. Abrol and V.V. Dhruva Narayana (Eds.), ICAR, New Delhi, India.

Valenzuela, C.R. 1988. ILWIS Overview. ITC Journal 1:4-14.

SOIL SURVEY FOR DEVELOPMENT AND GENERAL PLANNING PURPOSES USING THE LAND SYSTEMS APPROACH

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INTRODUCTION

Soil resource maps may be generated entirely by time-consuming field soil-survey. Some time can be saved by extrapolating information collected from one site to other, analogous sites, identified by their landscape patterns ie. the Land Systems approach (Christian and Stewart 1952). Remote sensing techniques can help in identifying the land systems and, within systems, land facets which are relatively uniform areas. In this approach, the survey activities follow three phases, viz. photo/ imagery interpretation, collection of ground truth, and collation of results.

As a case study, sample areas in Maharashtra State in India were studied. Maharashtra has a total area of 307,690 km², and is located between 15°38′ to 22°1 N latitudes and 72°39′ to 80°54′ E longitudes. The geological formations include basalt, gneiss laterite, and small areas of coastal sands and alluvium (Dikshit, 1985). Elevation ranges from 50 to 650m above mean sea level from coast to Deccan plateau, with the crest line ranging from 1000 to 1640m along the Western Ghats. The soil temperature regime is isohyperthermic and the soil moisture regime is Ustic (Van Wambeke 1985).

METHODS AND RESULTS

Landsat imagery was interpreted manually in association with existing topographic and soils data and, to cover each of the interpreted land units, sample areas were selected for study of soils. The data collected in the field were collated for preparing maps.
Three land systems were identified: the Konkan and Coastal Lowland, the Western Ghats (Sahyadris), and the Deccan plateau. Based on vegetation, drainage and terrain features the systems were divided into land facets and were studied for soil types and land use.

The Konkan and Coastal Lowland

Rugged land (Fig. 1). The rivers dissect basaltic plateaux in the north and laterite in the south. The annual rainfall ranges from 2000 to 3500mm. The plateaux are either covered with hard laterite or with very shallow, severely eroded and stony soils and are barren or under grass cover. The moderately to steeply-sloping mesas, ridges and hills are either rocky or stony or covered with soils similar to plateaux. These are either under grass or forest vegetation or cultivated to minor millets.

The side slopes of valley are covered with shallow Lithic Ustorthents, and are fairly suited for grazing and wildlife. The narrow valley floors are cultivated to rice, coconut and areca-nut. The side slopes could be managed through bench terracing and bunding, and the valley floors through stream check bunds and afforestation.

The spurs are covered with shallow skeletal Lithic Ustorthents, and are under grass or forest vegetation. These units are managed through afforestation, and cashew, casuarina and agave plantations.

The Western Ghats

The Western Ghats form the western edge of the Deccan plateau. They are dissected with steep sided valleys and ravines (Fig. 2). The annual rainfall ranges from 3500 to 6500mm.

The highly-dissected, moderately to steeply-sloping Sahydri hills; spurs on western slopes; and foot hills are covered with shallow, well drained, acidic, loamy-skeletal Typic Ustropepts and Lithic Ustorthents. These soils are stony and severely eroded. They are either under forest or cultivated to minor millets. These lands can be afforested or planted with cashew and mango.

The moderately to steeply-sloping, elongated ridges are covered with very shallow, loamy Lithic Ustorthents. The steep hill slopes are rocky. The soils are, again, stony and severely eroded. They would be most appropriately managed under forest or grassland. Moderately-sloping, narrow valley floors are covered with moderately-deep to deep, well drained, fine-loamy Typic Ustropepts and Udic Rhodustalfs. The soils are cultivated to minor millets, rice and vegetables in the rainy season. These units can be managed to avoid the present moderate erosion through afforestation and plantation of cashew, agave and mango.

The Deccan Plateau

East of Sahyadris extends the Deccan plateau, divided into a number of smaller plateaus and river valley plains (Fig. 3). This area receives 500 to 1500mm rain.

The moderately to steeply-summits and spurs of the upper and lower plateau carry very shallow, loamy to clayey, excessively to well drained soils with moderate erosion and moderate stoniness. These lands, in general, are non-arable. In places sorghum, pearl millet and groundnut are cultivated. The mesas and buttes in undulating lands carry Lithic Ustorthents and are either barren or under forest. These lands could be managed through afforestation.

The moderately-sloping, undulating lands are covered with moderately deep to deep Vertic and Typic Ustropepts. These land units are cultivated to sorghum and pearl millets in the rainy season. Contour bunding and levelling could be practised.

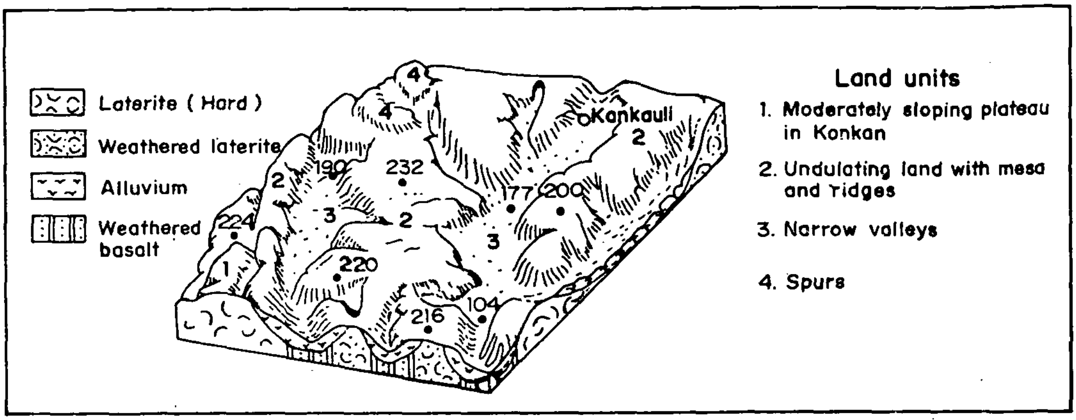

Fig. 1. Land units and soils of the Konkan and Coastal lowland system

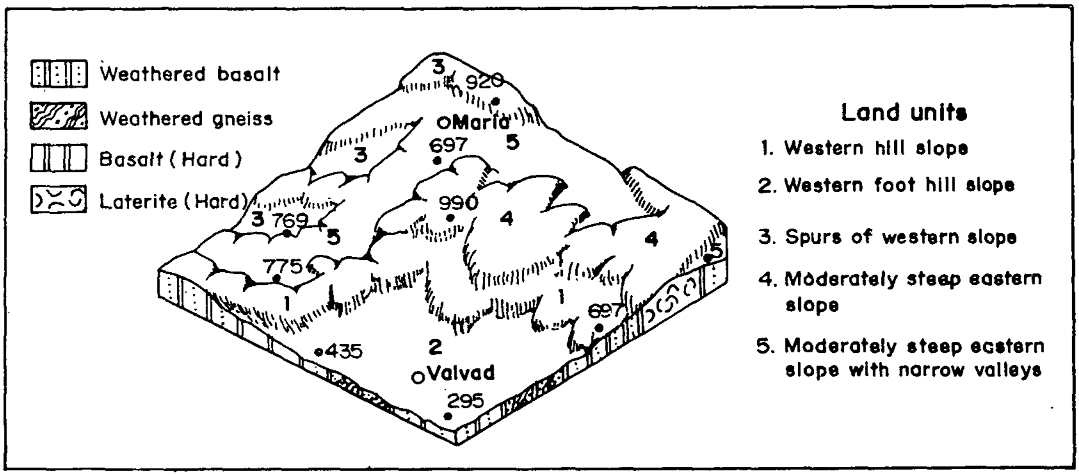

Fig. 2. Land units and soils of the Western Ghats land system

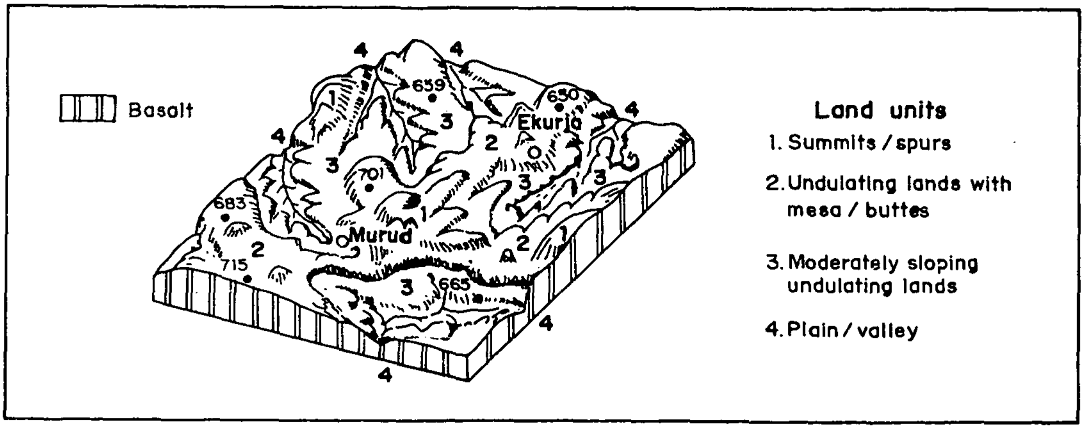

Fig. 3. Land units and soils of the Deccan Plateau land system

The gently-sloping valleys or plains consist of deep to very deep, well drained, cracking clay soils with moderate erosion. These soils are cultivated to sorghum, pigeonpea, sugarcane and irrigated cotton. The plain/valley units could be managed through proper soil and water management.

CONCLUSIONS

The land system approach can be used to generate quickly small-scale generalised maps of large areas for land use planning at a broad level. However, the main drawback of this approach is the limited number of observations confined to small areas which may, sometimes, lead to erroneous conclusions.

REFERENCES

Christian, C.S. and Stewart, G.A. 1952. *General Report on Survey of the Katherine - Darwin Region*. Land Research Series 1, CSIRO, Australia

Dikshit, K.R. 1985. *Maharashtra in Maps*: Maharashtra State Board for Literature and Culture, Mantralaya, Bombay, pp. 16-38

Van Wambeke, A. 1985. *Soil Moisture and Temperature Regimes of Asia*. SMSS Tech. Monogr. 9, Cornell University, Ithaca, USA

LAND SYSTEMS APPROACH FOR SOIL SURVEYS

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INTRODUCTION

There is ever-increasing pressure on land resources in India for meeting the food, fodder and fuel needs of the growing population. For increasing the productivity of land, basic information on resources is necessary. This could be achieved either by conducting separate surveys of various natural resources and, then, combining them in various ways to produce land resource maps; or by adopting the land systems approach where several factors are mapped simultaneously. A case study of the Kolar district, Karnataka was undertaken to illustrate the latter approach.

The Study Area

The Kolar district of Karnataka comprises 8223 km², situated between 12°46′ to 13°58′ N and 77°22′ to 78°35′ E. Average annual rainfall of 730 mm. Geological formations are Archaean granite and granite gneiss, Dharwar schists and quartzites, and Tertiary laterites. The elevation ranges from 600 to 1400 m above mean sea level. Natural vegetation consists of deciduous xerophytes and scrub. The important crops grown are finger millet, groundnuts and irrigated rice.

METHODS

Land resource maps of the Kolar district were prepared on scale 1:500 000 by applying the land systems approach using aerial photographs of 1:60 000 scale supplemented by the information from earlier reconnaissance soil survey. The procedure described by Shamacharya and Srinivasan (1972) was used to delineate land systems based on geology, landform and photo pattern. Systems were further subdivided into land facets by using photo tone and texture, relief and drainage patterns, and land use. Soil survey

data were incorporated to produce mapping units of associations of great soil groups. This map, in turn, was used for preparing maps of land capability and for soil-site evaluation for finger millet.

RESULTS AND DISCUSSION

The land system is defined as an area or group of areas having recurring pattern of topography, geology, geohydrology, soils and vegetation with a relatively uniform climate (Christian and Stewart 1952). Within a land system, a land facet is the smallest area that can be recognised and delineated within which, for practical purposes, environmental conditions are uniform (Dent and Young 1981).

Three land systems were identified. The Bagepalli land system covers 82 per cent of the study area on granite and granite-gneiss formations; the Sidlaghatta land system occupies 9 per cent of the area and is on laterite; the Bangarapet land system covers 6 per cent of the area and is on quartzite and schist formations. These land systems were subdivided into 15 land facets (Fig. 1) using photo elements. Soil composition for the land facets was inferred from the earlier reconnaissance soil map (Anonymous, 1988).

Bagepalli Land System

The Bagepalli land system is subdivided into 6 land facets, viz. isolated hills, hill ranges, rolling lands, undulating pediments, gently sloping pediments, and valleys. The isolated hills are rocky with no soil cover. The hill ranges are rocky with Ustropepts. The rolling lands and pediments have Ustropepts and Rhodustalfs with some rock outcrops. The valleys have an association of Ustorthents and Ustropepts.

Sidlaghatta Land System

The Sidlaghatta land system is subdivided into 3 land facets: coffin-shaped mounds, level colluvial plains, and broad valleys. Mounds have ironstone capping with Ustorthents in patches. Colluvial plains have an association of Haplustalfs and Paleustalfs. Valleys, dominantly Ustorthents, are intensively cultivated.

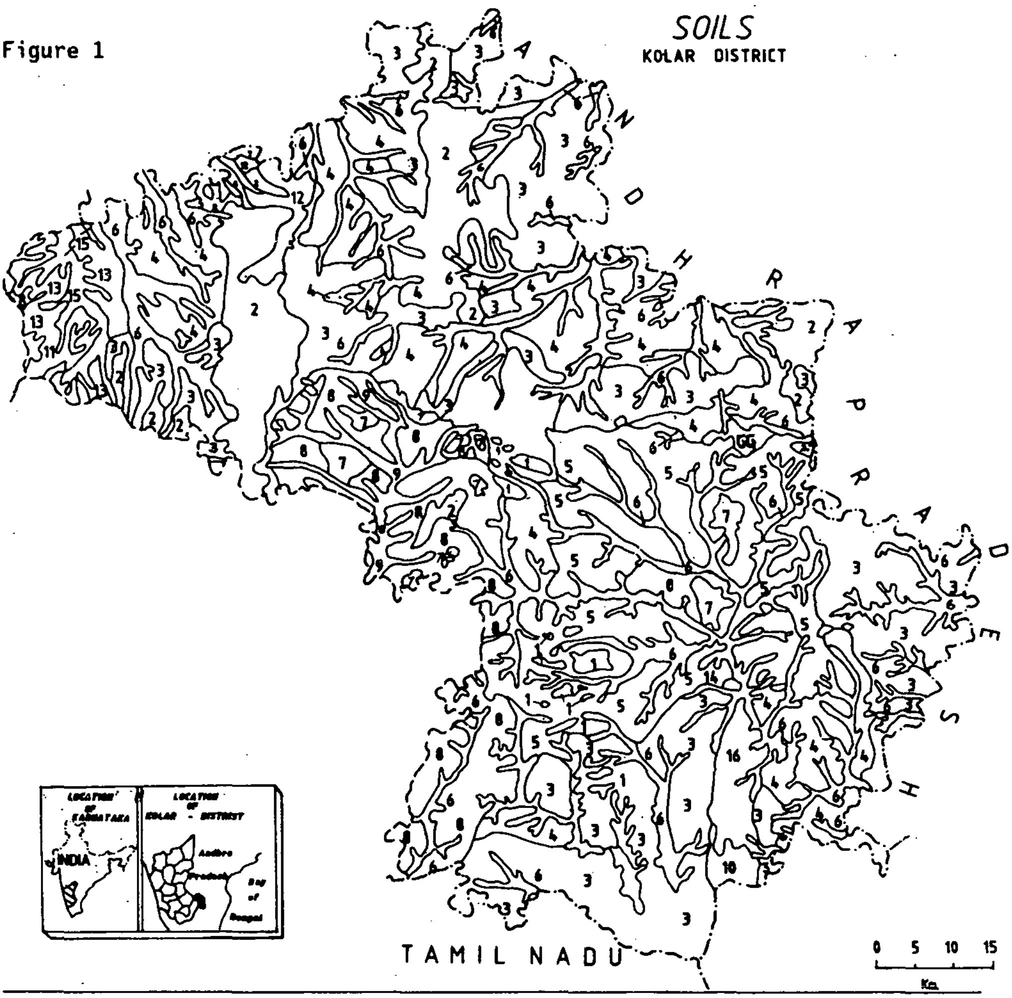
Bangarapet Land System

The Bangarapet land system has 6 facets: ridges, mounds, rolling lands, undulating and gently sloping pediments, and valleys. The isolated hills are rocky with no soil cover. The hill ranges are rocky with Ustropepts. The rolling lands and pediments have Ustropepts and Rhodustalfs with some rock outcrops. The valleys have an association of Ustorthents and Ustropepts.

Land Systems Approach to Land Use Planning

Land systems integrate a wide range of information about the land. The data can be used for delineating broad land resource regions and qualitative thematic maps.

Figure 1



Map Symbol	Facets	Soils	Area %
Bagepalli land system			
1.	Isolated hills	Rocky, no soil cover	1
2.	Hill ranges	Rocky outcrops - Ustropept	10
3.	Rolling lands	Ustropepts - Rhodustalfs	25
4.	Undulating pediments	Rhodustalfs - Ustropepts	22
5.	Gently sloping pediments	Ustropepts - Paleustalfs	9
6.	Valleys	Ustorthents - Ustropepts	11
Sidlaghatta land system			
7.	Mounds	Ustorthents - Laterite outcrops	1
8.	Colluvial plains	Haplustalfs - Paleustalfs	7
9.	Valleys	Ustorthents	1
Bangarapet land system			
10.	Ridges	Ustorthents - Rock outcrops	<1
11.	Mounds	Ustropepts	<1
12.	Rolling pediments	Ustropepts - Rhodustalfs	<1
13.	Undulating pediments	Ustropepts - Paleustalfs	2
14.	Gently-sloping pediments	Ustorthents 1	
15.	Valleys	Ustorthents - Ustropepts	<1

Land Capability Classification

The land capability map is based on standard NBSS and LUP practise, following the concepts of Klingebiel and Montgomery (1961). The 15 map units have been grouped into six land capability subclasses and, for each class, required conservation measures are indicated (Table 1). About 73 per cent of the area is suitable for agriculture, of which 29 per cent is good cultivable land (IIs and IIe) with minor limitations; about 43 per cent is moderately to fairly good land (IIIes-IVes); about 22 per cent of the area is not suitable for agriculture (VIe and VIII).

Soil-Site Evaluation for Finger Millet

Finger millet is grown as a mixed crop with Dalichos niger and fodder sorghum in uplands, and as a pure crop under irrigation in valleys. The soil-site characteristics considered important for growing finger millet were evaluated in terms of their limitations, and the overall suitability was determined based on the number and kind of limitations (FAO 1976 Sys 1978). The land facets were grouped into different suitability classes by matching the land attributes against the land requirements of finger millet. Only 7 per cent of the whole area is highly suitable (facet 8); 25 per cent moderately suitable (facets 5, 6, 9, 13 and 15), 44 per cent marginally suitable (facets 2, 3, 4, 7) and the remainder permanently not suitable (facets 1 and 10).

CONCLUSIONS

The study shows that the land systems approach can provide basic data for land capability classification and, also, for land suitability evaluations if fully supported by adequate field investigations and climatic data. Small-scale maps can be prepared speedily and economically for large areas.

Table 1. Land capability, Kolar District

Land capability subclass	Land facets	Limitations, suggested soil and water conservation measures	Area, ha (% total)
Lands suitable for agriculture			
IIs	6,9,15	Good cultivable valley lands with minor limitations of clayey texture in the subsoil, and alkalinity. Provision of adequate drainage should be made.	109100 (13)
IIe	5,8	Good cultivable lands with limitations of surface crusting, moderate sheet and gully erosion. Contour bunding, strip cropping and other dryland management practices needed.	133700 (16)
IIIes-	4,12,13	Moderate to fairly good lands with limitations of soil depth, coarse surface textures, gravelliness and stoniness, moderate to severe erosion. Contour or graded bunding with farm ponds, contour tillage and strip cropping needed.	212000 (26)
IVes	2,3	Fairly good lands occurring with rocky lands, about 50 per (Soilscent area in the units not suitable for agriculture; portion)major limitations are soil depth, gravelliness, stoniness, excessive runoff, slope and erosion. Diversion drains and plant cover required.	146100 (18)
Lands not suitable for agriculture			
VIe	7,10 11,14	Moderately sloping lands with limitations of soil depth, stoniness, surface crusting, topography and erosion. Graded bunding, check dams, diversion drains and permanent vegetative cover suggested.	27400 (3)
VIII	1,2,3	Rocky hills, rocky lands and gullied lands. (Rocky portion)	158600 (19)

REFERENCES

Anonymous, 1988. *The Soils of Kolar District (Karnataka) for Land Use Planning.* Soils Bull. 20, National Bureau of Soil Survey and Land Use Planning, Nagpur

Christian, C.S. and Stewart, G.A., 1952. *General report on survey of the Katherine-Darwin region, 1946.* CSIRO Land Research Series 1-30, Melbourne

Dent, D.L. and Young, A., 1981. *Soil Survey and Land Evaluation.* George Allen & Unwin, London

FAO, 1976. *A Framework for Land Evaluation.* Soils Bull. 32, Rome

Klingebiel, A.A. and Montgomery, R.H. 1961. *Land Capability Classification.* Agriculture Handbook 210, U.S. Dept. Agric., Washington, DC

Shamacharya, K. and Srinivasan, T.R. 1972. Use of small scale aerial photographs for the preparation of small scale soil map. Paper presented at 12th Cong. Intl. Soc. Photogrammetry, Ottawa

Sys, C. 1978. Evaluation of land limitations in the humid tropics. *Pedologie 28*:307-35

HYDROLOGICAL INVESTIGATIONS FOR LAND USE PLANNING: A CASE STUDY OF SAONGI CATCHMENT NEAR NAGPUR

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Nagpur, India

INTRODUCTION

Efficient use of limited soil and water resources is essential for increasing production and maintaining the productivity of land. Catchment-based land use planning involves the integration of soil and water conservation measures and improve agronomic, agro-forestry and silvi-pastoral programmes on a catchment-wide basis. Hydrological variables determining the management of the catchment are: soil-hydrological groups, peak runoff rates, volumes of runoff and sediment yields. In the present paper, hydrological parameters of the Saongi catchment are assessed in order to develop a management strategy for catchment-based land use planning, to study the effectiveness of soil conservation structures, and to study the effect of land use changes on quality and quantity of runoff.

Soils

The catchment comprises 74 ha with soils varying from shallow to deep, and from medium to fine-textured. Six mapping units have been delineated by detailed soil surveys; and there further grouped into three hydrological groups (Table 1).

The average annual rainfall in the catchment is about 1100 mm and this is received in about 7 or 8 runoff-producing storms, interspersed by long dry spells. Most of the runoff flows out of the catchment because of paucity of structures to harvest runoff.

Table 1. Estimation of runoff volume for each soil unit using the curve number technique (US Soil Conservation Service 1972)

Mappin Unit	Taxonomic Group	Area (ha)	Hydro-logic soil group	Land Use	Hydrologic condition	Curve number	Runoff (mm)
Sg-1	Lithic Ustorthent	2.7	B	Grazing	Good	77	166
Sg-2	Lithic Ustorthent	9.8	B	Row crops	Good	78	173
Sg-3	Lithic Ustochrept	39.3	C	Row crops	Good	85	226
Sg-4	Typic Ustochrept	11.0	C	Row crops	Poor	85	226
Sg-5	Udic Ustochrept	4.3	D	Row crops	Good	89	169
Sg-6	Typic Chromustert	1.6	D	Row crops	Good	91	170

Land use

The hills and escarpments bear grassland with scanty shrubs and trees, and are subject to uncontrolled grazing. At places, the rocks are exposed. The valleys contain shallow to deep soils and are under cultivation. Sorghum, cotton and pigeonpea are the principal rainy-season crops followed by mustard, gram and irrigated wheat. The overall land cover is rated fair to good by United States Soil Conservation Service standards.

RUNOFF POTENTIAL

To design soil conservation structures, both peak runoff rates and runoff volumes are required. The peak runoff rates were determined by both the Rational formula (Chow 1964) and Cook's formula (Hamilton and Jepson 1940), considering rainfall and watershed characteristics. The average peak runoff rate by two methods was taken as the design value. The peak runoff rate is 14.2 m^3 sec^{-1}. Runoff volumes as estimated by the USSCS curve number technique are presented in Table 1.

Sg-3 and Sg-4 soils produce more runoff than Sg-5 and Sg-6 soils. The runoff from the whole catchment, weighted by area of each soil unit, is estimated to be 187 mm ie. about 17 per cent of rainfall. This indicates the potential for very worthwhile water harvesting.

SOIL LOSS

At present, there are no gauging stations in the catchment at which soil and water loss can be measured. Therefore, soil loss values were determined from hydrologically-independent fields on different soils under different crop covers Table 2). Note that these measured, real runoff values are different from the estimated values in Table 1.

Table 2. Soil loss on different soils under various crop covers, (rainfall taken as 1100 mm)

Crop	Soil	Area of plot (ha)	Runoff (mm)	Soil loss (t ha^{-1} yr^{-1})
Pigeonpea + cotton (H-4) intercropped	Typic Chromustert	0.5	230	7.9
Cotton (h-4)	Typic Ustochrept	0.5	200	12.5
Pigeonpea	Lithic Ustorthent	1.0	300	8.5

Runoff volumes are greatest from the Lithic Ustorthent soils followed by Typic Chromustert and Typic Ustochrept. Soil loss values are highest under cotton in Typic Ustochrept, followed by pigeonpea in Lithic Ustorthent and pigeonpea plus cotton in Typic Chromustert. Pigeonpea intercropped with cotton tends to reduce soil loss because of its better canopy.

Soil conservation measures

Soil conservation measures in the catchment, undertaken with the help of Maharashtra State Department of Agriculture, include the construction of ditch-and-bund structures along the pediments to control grazing; the provision of graded bunds of 1 sq m cross-section to control runoff; and a water-harvesting tank to store runoff and recharge the ground-water.

REFERENCES

Chow, V.T. 1964. *Handbook for Applied Hydrology*. McGraw Hill, New York (Ref. for Rational formula)

Hamilton, C.L. and Jepson, H.G. 1940. *Stock water development: wells, springs and ponds*. US Dept. Agr. Farmers' Bull. 1859

U.S. Soil Conservation Service. 1972. *Hydrology*. National Engineering Handbook, Sector 4. Washington, D.C.

FROM LAB. TO LAND

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INTRODUCTION

An imbalance between food demand and production, on the one hand, and slow pace of traditional agriculture, on the other hand, call for the transmission of research data to farmers' fields.

The results of research are documented but, often, there are shortcomings. For example, the status of soil phosphorous and potassium may be mentioned but its release and fixation capacity not given. Salinity may be measured but the drainage and infiltration rates of the soil not recorded. Yield data may be presented but soils on which those yields were obtained not characterised. Hardly ever are the results of research evaluated against socio-economic conditions. All these faults in the design and reportirg of research severely impede its practical application.

The data on soil-crop responses are transferable to the extent that the site-specific influences are quantified. Thus, there is a need to characterise research sites and make available a complete set of data on site, soil and crop for effective transfer of research results to other sites that are comparable. Experiments should be done on defined soils. A pragmatic grouping of soils is essential for more general applicability of site-specific results. In general, the technology transfer requires a set of data on soils and adoptable crops. Examples of the significance of some important characteristics arediscussed below.

Soil Texture

It is observed from the Vertisol region around Nagpur, that the yield of sorghum is higher in clay and silty clay soils (18 to 21 q ha^{-1}) than silty clay loam soils (14 q ha^{-1}). The yields of cotton also increase with increasing fineness of texture: the maximum yield is recorded from clay soils. A priori, it is useful to know soil texture if yields are to be predicted.

Soil Moisture

In the cases above, crop yield might be more directly related to available water. There exists a significant relationship between moisture retention indices and soil separates, exch. Ca + Mg and CEC (Table 1). The ready reckoner based on these models (Table 2) can assist in computing available water capacity of soil.

These observations pertain to Vertisol soils of >30% clay.

Table 1. Regression function between moisture retention indices and related factors

		-33 kPa		-1500 kPa
Factors	r	Regression equation		Regression equation
Silt	0.692	Y = 12.548 + 0.869 silt	0.766	Y = 5.367 + 0.459 silt
Clay	0.939	Y = -15.820 + 1.109 clay	0.943	Y = -6.980 + 0.532 clay
Silt + Clay	0.903	Y = -9.176 + 0.606 silt + clay	0.945	Y = -4.743 + 0.303 silt + clay
Silt and Clay	0.946	Y = -15.801 + 0.185 silt + 0.966 clay	0.965	Y = -6.960 + 0.162 silt + 0.434 clay
as separate variables				
CEC	0.960	Y = 0.857 + 0.857 CEC	0.924	Y = 0.798 + 0.399 CEC
Exch. Ca + Mg	0.939	Y = 5.652 + 0.800 Ca + Mg	0.934	Y = 3.374 + 0.383 Ca + Mg

Table 2. Measured and predicted value of moisture and AWC (% w/w)

Particulars	Grouping soils on clay (%) basis		
	30-40	41-50	51-60
Texture	Sandy clay Sandy clay loam Clay loam	Silty clay Clay	Clay
Measured AWC	9-13	15-24	18-28
Predicted AWC on model:			
Clay	8-15	17-20	22-26
Silt	13-19	17-24	20-23
Silt + Clay	9-15	18-22	21-24
CEC	8-16	19-20	20-25
Ca + Mg	8-17	19-21	20-24
Silt and Clay as separate variables	9-13	17-22	21-26

The soil moisture potential for optimum plant growth may differ from one soil type to other as it does from one crop to another. Our own experiments on Vertisols indicate optimum wheat growth at soil water potentials between -100 and -900 kPa (Gajbhiye et al., 1990).

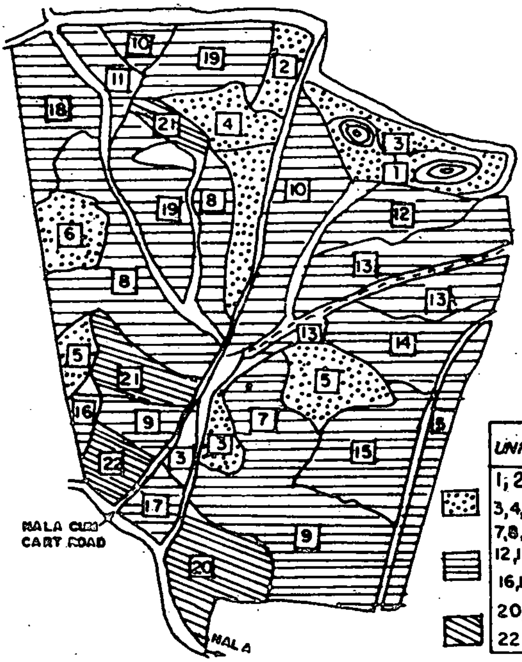
Cation Exchange Capacity of Soil

Sandy clay loam soils in the Nagpur region with CEC 35 cmol(P+) kg^{-1} produced paddy yields almost double those of soils with CEC 25 cmol(P+) kg^{-1}. Similarly, the effectiveness of liming was also greater by 10 per cent in higher CEC soils (Gajbhiye 1980). Of course, not all the difference in yields will all be due to the differences in CEC per se. Nevertheless, it seems that information on the CEC will help in making good predictions of yield.

Soil Fertility Status, Nutrient Requirement and Cropping Effect

In Saongi catchment, soils were categorised for the status of available K_2O (Fig. 1) as low (<75 ppm), medium (75-100 ppm), high (150-200 ppm) and very high (>200 ppm). Soils having low and medium status of available K_2O require K fertilization to maximise the production.

Monitoring soil fertility for targetted yields needs information on nutrient requirements to plan fertilizer application and crops differ in their requirements. For example, in alluvial sandy loam Holambi Series, pearl millet was found to be more nutrient exhaustive than wheat (Gajbhiye 1986). Though these crops belong to the same cereal family, their nutrient requirements to produce one quintal grain yeild differ considerably (Fig. 2).



UNIT NO.	SOILS	CLASSIFICATION	LEVEL OF AVAILABLE POTASSIUM (K2O)
1, 2	Sawangi - 1	Lithic Ustorthents	75-150 Medium
3,4,5,6	Sawangi - 2	Lithic Ustorthents	75-150 Medium
7,8,9,10,11 12,13,14,15	Sawangi - 3	Lithic Ustochrepts	151-200 High
16,17,18,19	Sawangi - 4	Typic Ustochrepts	151-200 High
20,21	Sawangi - 5	Udic Ustochrepts	> 200 Very High
22	Sawangi - 6	Typic Chromusterts	> 200 Very High

Figure 1. Level of available Potassium (K_2O ppm) in different soil series.

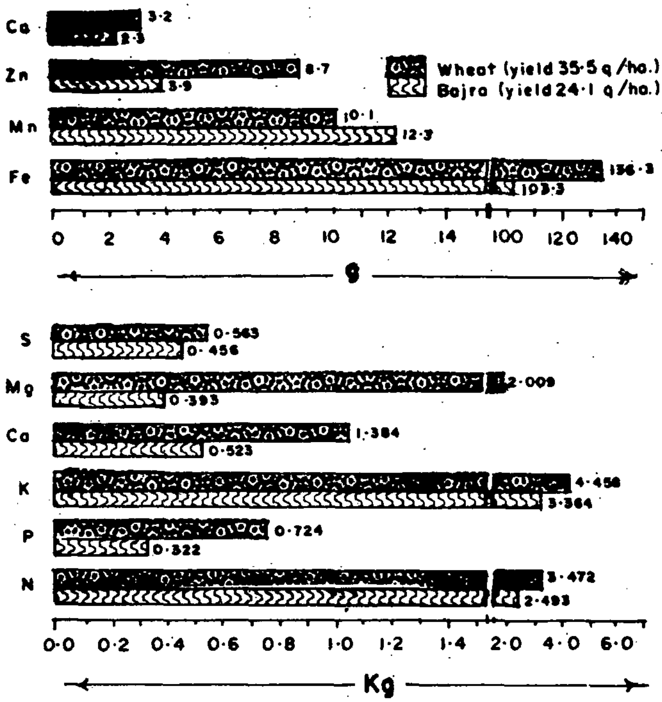


Figure 2. Nutrient requirement for production of one quintal grain yield.

Evaluation of fertilizers for a given soil-crop system is useful to economise on fertilizer input. Fertilization with K in Inceptisols and Entisols developed in alluvium (Gajbhiye and Gowaikar 1981) indicated 22 to 67 per cent fixation of applied K. The quantification of the factors (Table 3) responsible for K fixing capacity of soils would be helpful to develop models to compute the dose of K fertilizer for successful crop growth.

Table 3. Prediction model for K-fixation capacity of soil (Y)

Variable (X)	Corr.coeff.	Prediction equation
Org. Carbon	- 0.480	$Y = 72.29 - 100.15\ X$
Exch. K	- 0.442	$Y = 72.52 - 117.66 + 60.65\ X^2$
K/2 (Ca+Mg)	- 0.493	$Y = 72.84 - 221.25\ X + 250.72\ X^2$
0.5 N HCl-K	- 0.806	$Y = 82.08 - 35\ X$
Available K	- 0.758	$Y = 81.70 - 0.35\ X$

Appraisal of Salinity

Appraisal of soil and water salinity will be useful for screening crop varieties and to adopt suitable farming systems. Coarse sandy Aridisols of Rajasthan have been cultivated successfully for kharchia wheat, although irrigation waters are very saline (ECiw 2250-10000 μs cm^{-1}) with sodium absorption ratios between 15 and 35 (Gajbhiye and Kolarkar 1973). Effect of salinity on water holding capacity of Typic Chromusterts and Typic Ustochrepts indicated that, at comparable clay content, increasing the salt concentration increases the amount of water held at -33 kPa and -1500 kPa potential by 1 per cent with every unit of 0.5 EC (ds m^{-3}, 1:2.5 soil-water ratio). This would be useful to predict the soil water availability by introducing a correction factor.

Crop Production Potential

The agricultural value of soils around Nagpur with respect to crop husbandry is evaluated as very high, high, medium, marginal and low crop production potential (CPP) (Table 4). The marginal CPP rating indicates the minimum possible yield needed to be harvested to cover an expenditure on inputs, casual labour and sundry work for management of a given crop. The minimum possible yield expectation, assessed in terms of economic value as cost:benefit ratio, worked out to be 1:0.5 for cotton and 1:0.33 for wheat and sorghum. Such information is needed for evaluating the soils for different cropping systems.

Table 4. Crop Productivity Potential (CPP) rating

Note: Values in parentheses indicate the yield as a percentage of the maximum.

Soil subgroup	Cotton		Sorghum		Wheat	
	Yield ($q\ ha^{-1}$)	CPP rating	Yield ($q\ ha^{-1}$)	CPP rating	Yield ($q\ ha^{-1}$)	CPP rating
Typic Chromusterts	24.4 (100)	Very high	21.8 (98)	Very high	17.5 (83)	Very high
Udic Chromusterts	22.3 (91)	Very high	21.4 (96)	Very high	21.2 (100)	Very high
Entic Chromusterts	20.0 (83)	Very high	21.2 (95)	Very high	18.7 (88)	Very high
Typic Ustochrepts	12.2 (50)	Medium	22.4 (100)	Very high	16.0 (75)	High
Vertic Ustochrepts	12.7 (52)	Medium	16.4 (73)	High	11.6 (51)	Medium
Lithic Ustorthents	3.1 (13)	Low	17.6 (79)	High	7.5 (35)	Marginal

Acceptability by Farmers

To adopt innovations, farmers require a certain period of time. Besides the complexity of soil and climate, the diversity of socio-economic factors like population and its growth rate, land holding, market availability, communication, and the government policies on economic/sustainable/exportable or import substitution production all affect the process of technology adoption. It was recorded near Nagpur that the acceptability to the farmers of soybean cultivation increased after the second year of introduction and reached almost 90 per cent at the fourth year (Gajbhiye et al. 1988).

CONCLUSIONS

To secure self-reliance for agricultural products, traditional agriculture needs to be replaced by more scientific farming through the process of technology transfer. The whole set of useful information on a given soil-crop management system, both physical and economic, is very often lacking, or is segregated.

There is a need to tailor the research for specific agro-environments and socio-economic situations. If sites and situations are well-characterized, based on sound taxonomic principles, research knowledge can be transferred to other locations where similar conditions exist.

REFERENCES

Gajbhiye, K.S. 1980. Effectiveness of liming on rice yields in relation to CEC of soil. Indian J. Agron. 25:302-305

Gajbhiye, K.S. 1986. Studies on major and microelement requirement of wheat and bajra. J. Maharashtra Agric. Univ. 11:371-372

Gajbhiye, K.S., Gaikawad, S.T. and Hazare, T.N. 1988. Evaluation of farmers' preference and time requirement to adopt new agro-innovation of soybean cultivation around Nagpur. Maharashtra J. Extn. Edn. 7:41-45

Gajbhiye K.S., Gaikawad, S.T., Challa, O., Hazare, T.N. and Deshmukh, S.N. 1990. Evaluation of optimum range of soil moisture stress for establishment of wheat crop in Vertisols. J. Indian Soc. Soil Sci. 38:139-141

Gajbhiye K.S. and Gowaikar, A.S. 1981. Fate of applied K to some Entisols and Inceptisols of Punjab. J. Indian Soc. Soil Sci. 29:552-553.

Gajbhiye K.S. and Kolarkar, A.S. 1973. Quality of ground water in Bikaner district of W. Rajasthan. Ann. Arid Zone 12:65-70.

ROLE OF LABORATORY DATA FOR WATERSHED MANAGEMENT AND LAND USE PLANNING

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INTRODUCTION

Watershed management and land use planning are basically dependent on the inherent properties of soils, and judgement of land suitability for crop production needs information on the deficiencies and the excesses in respect of key properties. Analyses commonly carried out in soil survey laboratories include particle size distribution, bulk density, available water capacity, pH, electrical conductivity, cation exchange capacity, exchangeable cations, organic carbon, free iron oxide, available nutrients and calcium carbonate equivalent.

PHYSICAL PROPERTIES

Data pertaining to particle-size distribution are helpful for estimating erodibility, dispersion ratio, and available water capacity in the absence of moisture retention measurements. They are also required to classify soils at family level and for identification of diagnostic horizons as per Soil Taxonomy.

Bulk Density

Bulk density data can be interpreted in terms of soil porosity.

Available Water Capacity

Availability of soil water to plants decreases with decreasing water content, resulting in water stress on the crop well before the soil reaches permanent wilting point. This has led to the concept of readily available water, for which the upper limit is taken, somewhat arbitarily, as a soil water potential of -100 kPa (Milthrope 1960).

PHYSICO-CHEMICAL PROPERTIES

Soil pH

Soil pH gives information on a variety of other soil properties that are more difficult and, so, more expensive to determine, like availability of nutrients, exchangeable sodium percentage and consequent deterioration of structure (pH >8.5), and aluminum toxicity (pH <5).

Electrical conductivity

Conductivity of the saturation extract (ECe) is a rapid way of estimating soil salinity.

Cation exchange capacity and exchangeable cations

Data on cation exchange capacity and exchangeable cations help in evaluating soil fertility, in studying weathering and clay mineralogy, and in soil classification. FAO (1979) quotes CEC values of 8-10 cmol(P+) kg^{-1} soil for top 30 cm as indicative of minimum values for satisfactory crop production under irrigation, and less than 4 cmol(P+) kg^{-1} soil indicative of infertility. Landon (1984) rated CEC values of <5 cmol(P+) kg^{-1} soil as very low, 5-15 as low, 15-25 as medium, 25-40 as high and greater than 40 as very high.

CEC (pH 7)/clay ratio is an index of clay mineralogy. Morrison (1981) grouped soils with CEC/clay ratio of <0.2 as kaolinitic, 0.2-0.3 as mixed or kaolinitic, 0.3-0.5 as mixed, 0.5-0.7 as mixed or montmorillonitic and >0.7 as montmorillonitic.

Exchangeable acidity gives a measure of soil lime requirements. Only a few crops like tea, rubber, pineapple, tapioca and some tropical legumes can tolerate high exchange acidity.

Exchangeable calcium content of <0.8 cmol(P+) kg^{-1} soil is rated as low, 0.8-10.0 as medium, and >10.0 as high; for magnesium, ranges for low, medium and high are <0.2, 0.2-0.5 and >0.5; and for potassium <0.25, 0.25-0.5 and >0.5 cmol(P+) kg^{-1} soil, respectively. Deficiency of calcium is seen when pH is <5.5 or when exchangeable sodium is high or when there is high potassium. Ca:Mg ratio of >5 leads to magnesium deficiency (Landon, 1984). It is well known that high exchangeable sodium results in poor structure; also, it decreases availability of calcium, magnesium, iron and phosphorous and is toxic to plants.

Organic carbon

Organic matter contributes to CEC, N, P, and S. High organic matter helps in checking soil erosion through its stabilizing effect on soil structure and in soil moisture retention.

Available nutrients

Ratings of available nitrogen for crop production were given by Subbaiah and Asijah (1956) and that for phosphorous by Bray and Kurtz (1945) and Olsen et al. (1954).

Calcium carbonate equivalent

High levels of calcium carbonate (>15%) affect availability of phosphorous, magnesium and micronutrients.

Free iron oxide

High amounts of iron oxide adversely affect phosphorous availability.

CONCLUSIONS

Soil analytical data give quantitative information about physical and chemical properties which enhance the predictive value of soil survey. Modern equipment and techniques to speed up soil analysis, as used at the Tropical Soils Analysis Unit, will be helpful in providing quick analytical data support to soil surveys.

REFERENCES

Bray, R.H. and Kurtz, L.T. 1945. Determination of total organic and available forms of phosphorous in soils. Soil Sci. 59:39-45

FAO, 1979. Soil survey investigations for irrigation. Soils Bull. 42, Rome

Landon, J.R. (ed.) 1984. Booker Tropical Soil Manual. Booker Agric. Int., London reprinted in paperback by Longmans, London, 1991

Milthrope, F. 1960. Plant water relationship in arid and semi-arid conditions. Unesco, Paris

Morrison, R.J. 1981. Chemical criteria: methods of measurement and limits used in Soil Taxonomy. In Proc. South Pacific Forum on Soil Taxonomy, Institute of Natural Resources, the University of the South Pacific, Suva, Fiji

Olsen, S.R., Cole, C.V., Watanabe, F.S. and Dean, L.A. 1954. Estimation of available phosphorous in soils by extraction with sodium bicarbonate. Circ. 939, US Dept. Agric., Washington, DC, USA

Richards, L.A. 1954. Diagnosis and improvement of saline and alkali soils. Handbook 60, US Dept. Agric., Washington, DC, USA

Subbaiah, B.V. and Asijah, G.L. 1956. A rapid procedure for the estimation of available nitrogen in soils. Curr. Sci. 25:259-60

Walkley, A. and Black, I.A. 1934. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Sci. 37:29-38

WET COLOUR AND DRY COLOUR APPLICATION TECHNIQUES FOR PREPARATION OF SOIL MAP PROOFS

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INTRODUCTION

Suitable map printing techniques are needed to achieve the desired quality of soil maps and economy of time, labour and money.

This paper discusses two methods currently in use at the Ordnance Survey, Southampton and Soil Survey and Land Research centre, Silsoe, UK, viz. wet colour preparation (rub-on-proof) and dry colour application (Cromalin). These were applied to produce an hypothetical colour soil map proof of the Nagpur district, India, and a real soil map of the Wark Common Farm, Corn Hill-on-Tweed, Northumberland, UK.

MATERIALS AND METHODS

Soil map proof of Nagpur district

Using the wet colour application technique of the Ordnance Survey, the steps included were: 1) taking four negative prints of the base map over yellow astrafoil scribe coats; 2) preparing four printing plates; 3) obtaining a combined negative and twenty peel coats as per the colour scheme devised; 4) starting the printing process with the application of dye on sheet by using aforesaid material and tinted screens.

Soil map proof of Wark Common Farm

Using the dry colour application technique of the Soil Survey, the steps involved: 1) obtaining a farm map negative on film; 2) scribing the farm map on scribe coat; 3) preparing an overlay on transparent film and using the same for transparent positive; and finally 4) preparing seven peel masks and three tint screens for magenta, cyan and yellow. A piece of cromalin sheet was laminated and processed for printing with aforesaid material.

RESULTS AND CONCLUSIONS

Soil map proof of Nagpur district

A hypothetical soil map proof of Nagpur district (Figure 1 for a part of the soil map) was prepared on scale 1:250 000. 42 soil series units comprising of 182 delineations are shown. The units were depicted by varied colour shades. The significance of the proof lies in the clarity with which the different elements of information are depicted. They are discussed here in brief.

Basic shape: The triangular shape of Nagpur District was distinguished from yellow surface of the sheet in the background. The yellow surface indicated the continuity of the land surface as opposed to water bodies which are usually shown in blue.

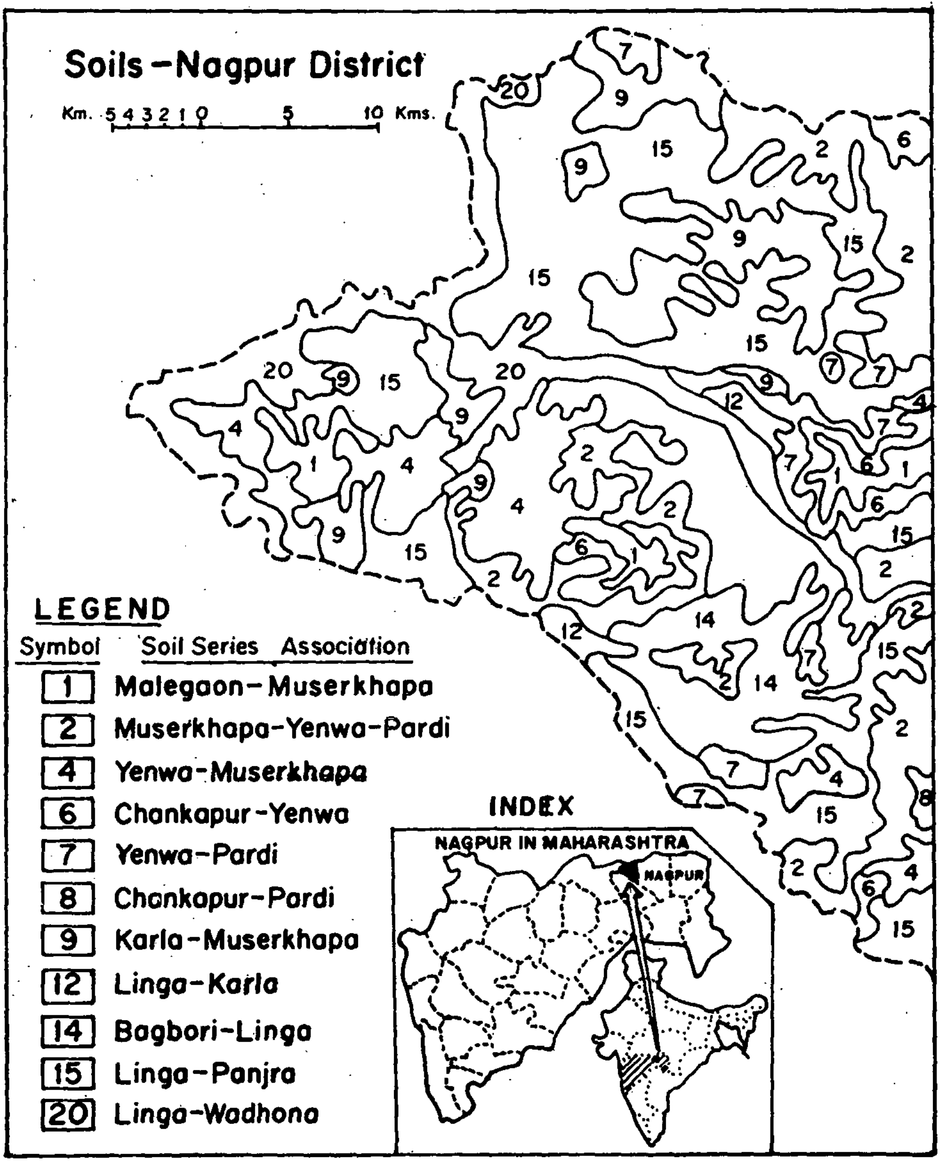


Figure 1. Soil map of a part of the Nagpur district, India.

Map design and layout: Design work involved lines, symbols, colours and lettering. Line work was carried out by scribers of different thickness eg. soil boundaries by point 200; physiographic boundaries by 300, drainage lines by 150. Roman and Arabic numerals were used as symbols to distinguish the physiographic units from the soil units. Colour selection for soil units was based on the D.O.S. colour chart.

Contents: Map contents were expressed by different colours and symbols. Distribution of soils were shown by different colours separated by black lines. Important rivers and tanks were represented by shades of blue; cities, towns and villages by light gray.

Visual levels: The soil map proof exhibited two visual levels: (i) soil map units in different colours that give, first and foremost, visual appeal; and (ii) base physiographic units, roads, railways and settlements as level two information.

Contrast and balance: Contrast in thickness of lines and colours was provided for easy perception of the soil information. Colour distinction was made by using GED screens of 25 per cent, 55 per cent and solid colours represented over the proof. Use of heavy lines and strong colours was avoided to maintain a balance among different graphic elements.

Choice of type face: UMCR and Rockwell fonts were used for physiography and the soil map legend. Legend letters were prepared on computer letter.

One problem that arose during the exercise was that some of the soil map units could not be depicted as per the devised colour scheme due to inadvertent peeling of the masks.

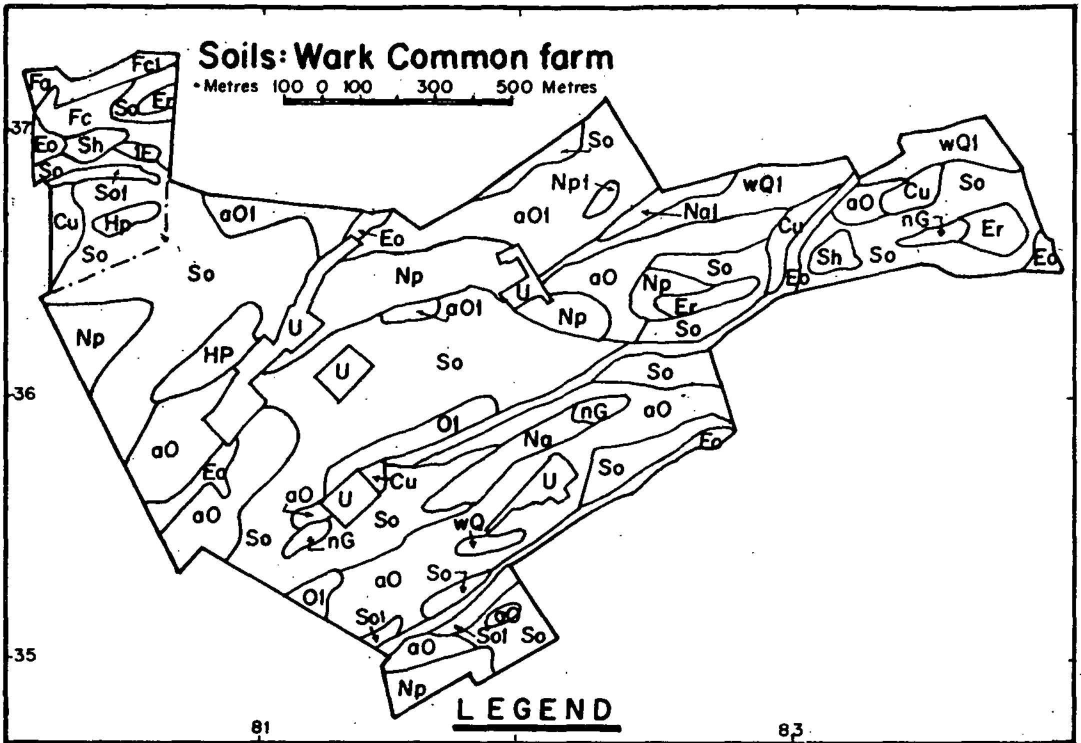
<u>Soil map proof of Wark Common Farm</u>

The soil map proof of the Wark Common Farm on scale 1:10 000 showed 21 soil series units and a few delineations of unsurveyed areas.

Orientation: The proof could easily be oriented as the title was placed at the top centre with a detailed legend at the bottom. The map was distinguished by multi-colour units enclosed by a thick black border separated from the blank background.

Clarity and simplicity: Unwanted geographical details were omitted from the map to increase its legibility. Map contents were clearly expressed by adopting two visual levels, viz. (i) coloured soil map units representing foreground image details; and (ii) base map details - like roads and settlements, indicated by black thin lines without disturbing the foreground image.

Colour contrast: For differentiation of the soil mapping units, eleven shades of magenta, cyan and yellow were generated by using the peel masks, tint screens, scribe coat and the negative. Some of the mapping units were combined to minimise peel masks and the plates for reducing the cost of production.



Symbol	Soil Series	Symbol	Soil Series	Symbol	Soil Series
Er	Escrick	aOl	Arrow (stony phase)	So	Salwick
nG	Newbiggin	HP	Hopsford	Sol	Salwick 3 (steep slope phase)
Na	Newport	Ol	Ollerton	Eo	Enborne
Nal	Newport (stony phase)	Fc	Flint	Fa	Fladbury
wQ	Wick	Fcl	Flint (steep slope phase)	fE	Freni
wQl	Wick (stony phase)	Np	Nupend	Cu	Clifton
aO	Arrow	Npl	Nupend (stony phase)	Sh	Salop
				U	Unsurveyed area

Figure 2. Soil map of Wark Common farm, Northumberland, UK.

Economy: Only 7 (instead of 21) peel masks and corresponding number of screens were used for printing the soil map. Separate colours for waterbodies and the map background were not prepared for reasons of economy.

Accuracy: Soil boundaries were skillfully scribed to obtain the desired accuracy. Soil units appeared as per devised colour scheme and no case of undershooting or overshooting was noticed on the proof.

CONCLUSION

The wet colour application technique is useful and economic for bulk production of small scale soil maps, but is time-consuming and expensive for the printing of a small number of copies of large scale maps. The dry colour application technique is economic and less time consuming for large scale soil map production.

ACKNOWLEDGEMENTS

The senior author expresses his sincere thanks to Messrs N. Chris, T. Chris, J. Gregg, M. Skegg, J. Hodgson and Ms Mina Mushkeri for their help during training exercises.

TECHNICAL SESSION ON LAND EVALUATION AND FARMING SYSTEMS

ECONOMICS IN LAND USE PLANNING

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THE ROLE OF THE ECONOMIST

The main role of the economist in land use planning is to assist in identifying land use options that are: (i) sustainable, (ii) financially attractive to the local communities and (iii) economically acceptable to society as a whole, and to compare these options. Sometimes there is conflict between physical and financial or economic assessments of land use options within a given area. There are cases, both in India and elsewhere, of land which has been classified as fit only for pastoral purposes being brought into cultivation because of population pressure. The families concerned in these cases have decided, for financial and social reasons, that this is the best use for those lands, irrespective of the recommendations made by physical scientists.

One can conceive of a spectrum of land uses with, at one end, high intensity cultivation based on well established farming systems and, at the other end, relatively unutilised and under forest cover or natural grasses. Land use in India falls mainly into the first of these categories and this is the one which involves economists most deeply because of the need to study existing economic systems, including the decision-making units within these systems. Economists can, however, make contributions at all levels of land use planning from the outline regional planning stage down to the individual farm level.

Almost the first requisite in land use planning is for planners to have a thorough understanding of existing land use patterns and of how existing farming systems tick. Without this, their recommendations may well be based on faulty premises and could be misleading. So it is at this level that the economist has a most important contribution to make. He must study farming systems, as entities, and the context within which they are set. At the farm level, he must become conversant with the scale and quality of the resources at the disposal of farmers. He must assess prospects for marketing new products or expanding sales of existing products. He must also assess local institutions providing credit, marketing and development services and make a judgement on how effectively they are performing their respective roles. He will be concerned with tenure, including land distribution in the community, and he should pay particular attention to how landless people and women might be affected by proposals for improvement in land use.

Some of the information required has to be collected at first hand but not all of it, because hundreds of farm management and village-level studies have been carried out and recorded in India. However, the economist will usually have to collect additional data to bring previous reports up to date and in order to analyse land use options in sufficient depth.

KEY CONCEPTS

The analyses carried out by the economist can range from a broad, macro-level assessment which complements reconnaissance level land evaluation studies, through appraisal of individual projects and programmes, down to analyses at individual farm level. Two distinct types of analyses are carried out, viz. "Financial" analyses using actual market prices and costs, and "Economic" analyses based on the true value and cost of products and resources to the economy as a whole. The main different between the two is that, in the economic analyses, adjustments are made to correct for the distorting effects of subsidies on farm inputs, sales taxes and price fixing which cause actual prices and costs to vary from their true levels. Labour, including family labour, is valued at its opportunity cost, that is the contribution it would make to the economy in its most productive alternative use.

Another important concept is "discounting". Its rationale is that production or consumption now is preferable to production or consumption at some time in the future. In other words, future values are worth less than present values. Because of this, when we are comparing streams of annual benefits associated with particular land use options, we have to discount these values at an appropriate percentage rate to provide a fair basis for comparison. The "present values" of the benefit streams are then compared to their initial costs and a decision taken on which option is to be preferred.

INTERACTIONS WITH PHYSICAL SCIENTISTS

Economists rely on physical scientists (soil scientists, agriculturalists, foresters, livestock specialists and so on) for most of the physical information used in economic and financial analyses, such as input levels, yields, rotations, crop growth periods. Physical scientists are, at times, wary of providing other than very approximate data on these variables. However, this exercise does encourage them to focus more explicitly on the assumptions incorporated in land suitability assessments.

Economists can also help to ensure the physical scientists do not ignore people-related aspects of land use planning. Farmers' perceptions of proposals for improving land use can vary from those of the "disinterested" scientists who generate such proposals. An important function of the economist is to help design proposals that are attractive to prospective adopters as well as being technically feasible.

Land use planning is particularly problematic in areas where, within a small compass, there exists a variety of farming systems, different sizes of holding and forms of tenure, and levels of operation ranging from large-scale commercial to small-scale subsistence agriculture. There is no readily-applicable way of dealing with such areas. However, the economic and social problems presented in such areas must be addressed systematically if proposals for land use improvement are to stand any chance of successful application. The easy but unhelpful way out is to prepare land use plans on a purely physical basis.

On their side, physical scientists can help ensure that the models used by economists are realistic in terms of crop rotations and growth periods, input/output relationships, pest control, and physical sustainability. They should not permit economists to be carried away by the sophistication of some techniques of economic analysis.

Physical scientists and economists should collaborate in the production of reports on their joint studies, rather than reporting separately. Contributions from both sides should appear between the same covers, and within the body of the report the two approaches should be integrated as far as possible rather than treated independently of each other.

PROBLEMS OF ECONOMIC ANALYSIS

Economic and financial analyses of rural development are problematic: data are often of doubtful reliability, benefits which extend well into the future (30 years or more) are difficult to handle, there is considerable uncertainty over future prices and cost levels, it is people who take decisions regarding resource allocation and innovation and their motives and criteria for decision-making are not always obvious and, of course, their views, attitudes and capabilities can all change over time.

Because there are these problems, the results of financial and economic analyses must be interpreted with caution. They are not the last word because they are based on a great many assumptions, some of which may turn out to be invalid. That said, it is usually helpful to draw on the best data and estimates at one's disposal as an aid in decision-making, even though the data may have weaknesses.

AN IN-HOUSE UNIT

The points and issues covered in this paper raise the question of whether land use planning in an organisation like the NBSSLUP can best be served by combining NBSSLUP's expertise in land resource assessment with that of other organisations, such as the State Agricultural Universities, which have strength in agricultural economics, or whether a small agricultural economics unit should be established in-house to work alongside and exert a continuing influence on physically-minded scientists. I admit to having a preference for the latter option but I leave the question posed.

DISCUSSION

Question (Dr Wantchedi): In economic analysis of soil conservation measures, an attempt is generally made to take indirect benefits into account. The results can sometimes be misleading. Is there any method by which the gain from soil conservation can be properly converted to monetary terms?

Question (Dr Gaikawad): What techniques of economic analysis are available for assessing environmental benefits resulting from soil and water conservation measures?
Answer (to both questions): It is quite difficult to carry out a comprehensive cost-benefit analysis of soil and water conservation measures for two main reasons. First, the downstream effects of reductions in soil erosion are difficult to assess and, secondly, measurement of the on-site benefits is also problematic because of lack of data on gains associated with conservation measures and the pattern of these gains over time. I know of very few cases where a comprehensive analysis has been successfully carried out under field conditions in developing countries. There is no specific methodology that can help; the problem is one of quantification.

Question (Dr Sagre): Is it more feasible to evaluate intercropping or sole cropping?
Answer: Sole cropping is easier because measurement of inputs and output is simpler and the benefits are attributable to a single crop. With intercropping, it can be difficult to define what each component of the mixture is contributing and is also difficult to allocate labour and other inputs to individual crops. In the absence of good input-output data, there can be not reliable datum against which possible improvements in intercropping systems can be assessed. Nevertheless, intercropping is popular with farmers for reasons that are well understood. It is important, therefore, that the more common intercropping systems are evaluated one against the other and for comparison with sole cropping.

Question: How is it that conceptually-attractive systems of farming including agroforestry, alley cropping, vegetative bunds and so on are not favoured by farmers?
Answer: There are various possible reasons: (i) on average, the return from these systems may to too low; (ii) scientists themselves sometimes overestimate the benefits that can be obtained from these systems under realistic, farm-level conditions; (iii) farmers may believe that, on average, they will benefit but do not wish to face the uncertainty associated with innovation.

Question: Does non-adoption of these innovations mean that economic factors have not been accounted for each step of the research effort and, if so, what approach should we take to further research?
Answer: We must be very sure about two things: the intrinsic merits of the proposed systems, and their suitability for adoption at farm level. It is not good defining 'improved' systems before these two prerequisites have been met.

METHODS OF LAND EVALUATION

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INTRODUCTION

The demands placed on finite natural resources are increasing exponentially due to growing population and increasing economic activity. To meet increased demands and, at the same time maintain the productivity of the land, we will have to manage our natural resources more effectively than we do now. The justification for systematic surveys of natural resources has been that with this basic information it is possible to evaluate the potential of different kinds of land for different land use options, and devise land use plans that are appropriate to each locality and profitable to the land users.

Natural resource surveys provide basic data. Decision-makers need interpretations of the basic data in order to take informed decisions about land use. Land evaluation is the process of interpreting the potential of land. It can be qualitative or quantitative, depending on its purpose and on availability of data. In this paper, we review most widely-adopted methods of land evaluation, viz. USDA land capability classification, USBR irrigation suitability system, parametric methods and the FAO Framework for Land Evaluation.

LAND EVALUATION METHODS

Land Capability Classification

One of the earliest and certainly the best known soil survey interpretations is the USDA land capability classification (Klingebiel and Montgomery 1961). This groups soil mapping units according to their capability of producing field crops, pasture and forest on a sustained basis. It is based on measurements of permanent physical characteristics of the land but it does not specifically take into consideration the requirements of different kinds of land use, management levels or economics, although assumptions about these are implicit.

The Land Capability Classification has three levels of classification (Table 1). Capability classes are arrived at by grouping the soil mapping units according to their capability for use without causing unacceptable levels of soil erosion. These classes are divided into sub-classes according to the main limitations to use, specifically erosion hazard, wetness, soil and climatic limitations. The sub-classes may be, in turn, divided into land capability units based on specific soil management requirements, though this third level of classification is not often used and can only be used if the classification is based on detailed soil maps.

Table 1. Structure of Land Capability Classification (from Dent and Young 1981)

Capability Class		Capability Sub-class	Capability Unit	Soil Mapping Unit
Arable	(I			
	(II	IIe, erosion	IIe-1	A Series
	(III	IIw, wetness	IIe-2	B Series
	(IV	IIs, soil	IIe-3	
		IIc, climate		
		IIes		
		etc.		
Non-arable	(V			
	(VI			
	(VII			
	(VIII			

This system was designed for farm planning. However, because of its simplicity of presentation, it has been widely applied for different purposes. For example, at the national and regional levels, it has been applied at class and sub-class level to indicate the flexibility of land use, and the main limiting land characteristics.

As Shaxson (1981) has pointed out, it is not so much a Land Capability Classification as a Land Incapability Classification. It is based on limitations to use rather than opportunities for use. Another shortcoming is that the classification is based on permanent limitations and no consideration is given to land characteristics, like soil nutrients and impeded drainage, that can be improved by the farmer.

USBR Land Classification

This is a simple financial evaluation for irrigated agriculture (USBR 1953). An attempt is made to integrate the physical features of land and the economics of land development in an estimate the 'payment capacity' of the land, ie. its ability to repay the cost of the initial investment.

The attraction and, indeed necessity of a financial assessment is obvious and this system has been used very widely for planning irrigation projects. Each assessment is, however, site specific. The limits selected for establishing the classes and costs and benefits must be prepared anew for each project.

Productivity Indices

Very many attempts have been made in different parts of the world to develop 'productivity indices' for land evaluation. Of these, the Storie Index (1933 and subsequent revisions) is the best known. The index is derived empirically from local relationships between the land characteristics and productivity. Therefore, it cannot be transferred to other areas with different technological levels or environments.

The more complex parametric method of Riquier et al. (1970) illustrates clearly the drawbacks of this approach. Nine soil properties are selected, each of which is rated on a scale of 0-100 for a particular land area. The ratings are multiplied to arrive at an index of productivity. In this kind of system, the more factors considered, the lower the rating will be. The choice of factors, and the rating and weighting of each factor is subjective. Moreover, interactions between factors cannot be considered. Parametric systems are suitable only for the local areas for which they are developed and tested, and are not suitable for universal application.

The FAO Framework

Earlier systems of land evaluation grade the land from best to worst irrespective of the kind of land use and level of management. Such a 'one shot' land evaluation cannot provide the information needed to make a choice to be made between several land use options. To make a choice we need to know the consequence of applying each specified management to each particular parcel of land. The FAO Framework for Land Evaluation (FAO 1976) was devised to meet this need. It is not a procedure for land evaluation, but a set of principles from which land evaluation procedures can be developed to suit the local conditions. More detailed guidelines on procedure have been published as guidelines (for example FAO 1983, 1985).

There are two suitability orders, 'suitable' and 'not-suitable'. Suitable means that the sustained use of the land will yield benefits which justify the inputs without risk of damage to the land. Not-suitable means that the land is not suitable for sustained production under the prevailing conditions. Land suitability classes reflect the degree of suitability within orders; sub-classes reflect the kinds of limitations within classes; suitability units maybe defined within each sub-class units based on their response to management.

This outward structure is not unlike land capability classification but the approach is very different. In the first place, specific land use types (LUT's), equivalent to cropping systems, are identified and described. Next, the requirements of each LUT are established in terms of land qualities, either positively as requirements, or negatively as limitations. A 'land quality' is defined as a complex attribute of land that acts in a specific way to affect the performance of the land use type. The concept of land qualities has been developed to take into account the interactions between land characteristics. For example, the land characteristic 'slope angle' may act negatively on land use where increasing slope means increasing erosion; or it may act positively where increasing slope means better drainage. It is useful to express land qualities in terms of sufficiency (Melitz 1986), for example, 'sufficiency of water', or 'sufficiency of nutrients' (Table 2), there being a direct relationship between the degree of sufficiency and crop performance.

Table 2. Land Qualities (Relevant Soil Characteristics)

Hazard of Erosion (structure texture drainage class slope angle, degrees slope length, m position on slope)	**Sufficiency of Air** (drainage class)
Sufficiency of Energy (Soil temperature regime topsoil texture drainage class colour)	**Sufficiency of Nutrients** (texture parent material degree of weathering pH organic matter rooting depth)
Sufficiency of Water (Texture stones rooting depth salinity shedding/receiving site)	**Hazard of Toxicity** (pH soluble Al soluble B)
	Workability (consistence texture stones)

It may be possible to measure a land quality in terms of a single, mapped land characteristic. For example, the quality 'hazard of toxicity' may be estimated just from pHbut, usually, several characteristics have to be combined in a model. For example, the quality 'sufficiency of water' must encompass meteorological evaporative demand, crop leaf area, effective rainfall and the crop-available water capacity of the soil. (See Giri et al, this workshop).

The initial land suitability classification will be bio-physical. If it can be expressed in terms of yield, and inputs needed to achieve this yield, then financial and economic evaluation, including risk, and environmental impact assessments can then be undertaken.

There are problems in using the FAO Framework: the concept of 'land quality' is more difficult to understand than the concept of a single land characteristic; the procedures for assessing the interactions between different characteristics that determine a land quality are complex; there are difficulties in getting acceptable and reliable information for carrying out economic, social and environmental analysis. The whole analysis becomes extraordinarily complex and time-consuming. A separate exercise is needed for each crop, and no standard procedure has been devised for the complex intercropping systems used by smallholders in most tropical areas.

CONCLUSIONS

The trend in land evaluation has moved towards crop-specific evaluations, and from qualitative to quantitative, so that economic criteria as well as physical criteria can be applied. The result is that ever-more-specific information on land characteristics and land qualities, farming systems and crop requirements is needed. This is a problem for the professionals but it is not a problem for the decision-makers, since the professional output is, at least in intention, more specific, less ambiguous, and easier to use in decision-making.

REFERENCES

Dent, D.L. and Young, A. 1981. *Soil Survey and Land Evaluation*. George Allen & Unwin, London

FAO, 1976. *A Framework for Land Evaluation*. Soils Bull. 32, FAO, Rome

FAO, 1983 *Guidelines: land evaluation for rainfed agriculture*. Soils Bull. 52, FAO, Rome

FAO, 1985. *Guidelines: land evaluation for irrigated agriculture*. Soils Bull. 55, FAO, Rome

Klingebiel, A.A. and Montgomery, P.H. 1961. *Land Capability Classification*. Agric. Handbook 210, Soil Conservation Service, US, Dept. Agric., Washington DC

Melitz, P.J., 1986. The sufficiency concept in land évaluation. *Soil Survey and Land Evaluation* 6, 1, 9-19

Riquier, J., Bramao, D.L. and Cornet, J.P. 1970. A new system of soil appraisal in terms of actual and potential productivity, FAO-ADL: TESR/7016, Rome

Shaxson, T.F. 1981. Determining erosion hazard and land use incapability, a rapid subtractive survey method. *Soil Survey and Land Evaluation* 1: 44-50

Storie, R.E. 1933. *An index for rating the agricultural value of soils*. Bull. 556, Agri. Exp. Stat., California, USA

US Bureau of Reclamation, 1953. *Bureau of Reclamation Manual Vol. V, Irrigated Land Use, Part 2, Land Classification*, Denver, Colorado, USA.

APPLICATION OF THE FAO FRAMEWORK FOR LAND EVALUATION TO CATCHMENTS IN INDIA

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INTRODUCTION

If soil survey data are to be useful for land use planning, they must be interpreted for the purpose in hand. This requires a significant amount of work, including field work, in addition to that needed for the soil survey (Dent and Young 1981).

In land evaluation, we can rank areas of land according to their suitability for a range of land use options, or we can try to make quantitative predictions of the production that can be obtained and the inputs needed to achieve that production. These quantitative data may then be subjected to economic analysis.

Following the FAO Framework for Land Evaluation (1976), the first step is to describe the land use types for which evaluation is being carried out and to establish their land requirements. Land requirements are specified in terms of land qualities: these are attributes of land that directly affect crop performance or the sustainability of the land use type (see Natarajan and Dent, this workshop).

Even this first step presents practical difficulties, because information about land requirements is widely scattered and of uneven quality, even for major crops. Also, soil and agroclimatic data are not available in the form that can be used directly in matching crop requirements with land qualities.

This paper describes attempts to apply the principles of the FAO Framework in a qualitative way to three catchments: Saongi, near Nagpur; Wankaner, near Vadodara; and Nainwal, near Delhi; and the use of field trial data in Saongi to quantify the assessment of crop yields.

The Study Areas

The Saongi catchment has a subtropical, subhumid climate. The soil moisture regime is ustic with mean annual rainfall of 1125mm, and temperature regime is hyperthermic. The soils, Saongi-2 (shallow loamy sand), Saongi-3 (shallow loamy sand), Saongi-4 (moderately deep gravely sandy clay), Saongi-5 (very deep silty clay) and Saongi-6 (very deep clay) are, respectively, Lithic Ustorthents, Lithic Ustochrepts, Typic Ustochrepts, Udic Ustochrepts and Typic Chromusterts.

The climate of Wankaner and Nainwal catchments is semi-arid with mean annual rainfall of 600 to 900mm. The soils are very deep, sandy loam to loamy sand, slightly to severely eroded, and occur on gentle to moderate slopes.

PROCEDURE AND RESULTS

First, a detailed soil survey was carried out in each catchment. Then, from a literature search and personal experience (Bhaskar et al. 1987, Gaikawad and Bhaskar 1988, Gaikawad et al., 1990) tables of land requirements were drawn up for each crop and a judgement made of appropriate values limiting values for each diagnostic land characteristic for suitability classes S1, S2, S3, N1 and N2. The arbitrary or qualitative nature of some of these judgements, summarised in Tables 1, 2 and 3, highlights the need for a specific program of research in land evaluation.

Productivity evaluation trials were conducted in Saongi catchment only. Gross margins were calculated for each crop for each land suitability class. These results are shown in Tables 4 and 5.

Table 1. Criteria for assessing land suitability for cotton

Land Qualities (requirements and diagnostic land characteristics)	Suitability class and subclass				
	S1	S2	S3	N1	N2
Sufficiency of energy					
Mean temp. during germination, °C	18-30	30-35	35-38	38-40	> 40
Mean temp. during growth, °C	22-30	30-35	30-35	35-40	> 40
Mean temp. during ripening, °C	27-32	32-35	35-38	38-40	> 40
Sufficiency of water					
Mean annual rainfall, mm	>900	800-899	600-799	400-599	<400
Soil water availability mm/m	>350	275-350	120-274	80-119	< 80
Rooting depth, cm	>120	60-119	40-59	20-39	< 20
Sufficiency of air					
Soil drainage class	well	mod. well	imperfect v. poor	poor,	not relevant
Conditions affecting germination					
Soil texture	ZC,ZCL	C,SCL	SL	-	-
Sufficiency of nutrients					
Nutrient availability	v.high	high	medium	low	not relevant
Hazard of erosion	slight	slight	moderate	severe	v. severe
Ease of cultivation					
Workability	easy	moderate	difficult	v. difficult	not relevant

Table 2. Criteria for assessing land suitability for sorghum

Land Qualities (requirements and diagnostic land) characteristics	Suitability class and subclass			
	S1	S2	S3	N1 N2
Sufficiency of energy				
Mean temp. during germination,°C	24-30	30-35	35-38	38-40>40
Mean temp. during veg. growth,°C	25-28	20-25	18-20	15-18<15
Mean temp. during ripening,°C	30-35	25-30	22-25	18-22<18
Sufficiency of water				
Mean annual rainfall, mm/m	>700	700-600	600-500	500-400<400
Soil water availability mm/m	350	275-349	120-274	80-119< 80
Rooting depth, cm	>80	60-80	40-59	< 40< 40
Sufficiency of air				
Soil drainage class	well	mod. well	imperfect v. poor	poor, not relevant

Table 3. Criteria for assessing land suitability for wheat

Land Qualities (requirements and diagnostic land) characteristics	Suitability class and subclass			
	S1	S2	S3	N1 N2.
Sufficiency of energy				
Mean temp. during germination,°C	15-20,20-25	12-18,22-25	10-15,25-28	8-12,28-30not relevant
Mean temp. during veg. growth,°C	8-10	10-12	12-15	15-2020-30
Mean temp. during ripening,°C	20-25	22-25	25-30	28-3530-40
Sufficiency of water				
Mean annual rainfall, mm/m	>700	700-600	600-500	500-400<400
Soil water availability, mm/m	170-200	150-170	80-150	< 80< 80
Rooting depth, cm	70-100	50-70	20-50	< 20< 20
Sufficiency of air				
Soil drainage class	well	mod. well	impferect v. poor	poor,not relevant

NOTE: Sufficiency of nutrients, hazards of erosion and ease of cultivation for sorghum and wheat were assumed to be similar to those for cotton (Table 1).

Table 4. Production efficiency and economic significance of different soils to crops (1987-1989)

	Mean Yield (q ha^{-1})			Production efficiency	Cost of Cultivation (Rs.ha^{-1})			Net return (Rs.ha^{-1})			Gross margin
	Sorghum	Cotton	Wheat	(%)	Sorghum	Cotton	Wheat	Sorhgum	Cotton	Wheat	(Rs.ha^{-1})
Saongi-6 Typic Chromusterts	38.1	15.0	23.3	23.5	4556	6590	5112	6503	6580	3508	16591
Saongi-5 Udic Ustochrepts	43.8	17.3	26.1	26.8	4546	6798	5084	8156	8312	4573	21041
Saongi-4 Typic Ustochrepts	25.8	11.4	21.3	18.0	4332	6454	5022	3150	3555	2752	9457
Saongi-3 Lithic Ustochrepts	22.8	10.3	21.6	16.8	4323	5726	5012	2397	3317	2868	8582
Saongi-2 Lithic Ustorthents	21.5	8.2	18.6	14.9	4237	4958	5736	1568	2241	1690	5499

* Where sorghum, cotton and wheat yield @ Rs. 200, 850 and 300 q^{-1} and sorghum, cotton and wheat byproudcts @ Rs. 50, 20and 50 q^{-1}, respectively.

Table 5. Correspondence between crop performance and suitability class

suitability class	Mean Yield (q ha^{-1})			% yield increase over S3 soils		
	Sorghum	Cotton	Wheat	Sorghum	Cotton	Wheat
Highly suitable (S1)	41.7	14.0	30.5	62.3	62.8	72.9
Moderately suitable (S2)	30.3	9.5	21.0	17.9	10.5	18.6
Marginally suitable (S3)	25.7	8.6	17.7	--	--	--

In summary, the deeper soils of Saongi catchment were judged to be highly suitable for all the crops studied and the shallower soils marginally suitable or not suitable, the ranking of suitability followed the sequence - Udic Ustochrept > Typic Chromusterts > Typic Ustochrepts > Lithic Ustochrepts > Lithic Ustorthents.

Further, the better soils are financially 3 to 4 times as profitable as the poorest under the same system ofmanagement. In the Nainwal catchment, soils were mostly moderately or marginally suitable for pearl millet, wheat and mustard but a few more judged to be highly suitable for pearl millet and mustard. In the Wankaner catchment, most soils were judged to be moderately suitable for tobacco, pidgeon pea and pearlmillet, but a few were highly suitable for tobacco.

DISCUSSION

The comparison between productivity, profitability and the physical assessment of land suitability for the Saongi catchment (Table 5) shows a clear correspondence.

This gives us confidence that a useful ranking of soil mapping units from most suitable to least suitable can be achieved using the kinds of data already available from soil surveys. With field crop trials, and farm management data, this ranking can be converted to coarse estimates of productivity under different systems of management.

REFERENCES

Bhaskar, K.S., Lal, S., Challa, O. and Madavi, S.H. 1987. Effect of soil depth on cotton yield. J. Maharashtra agric. Univ. 12:139-140

Dent, D.L. and Young, A. 1981. Soil Survey and Land Evaluation. George Allen & Unwin, London

FAO, 1976. A Framework for Land Evaluation. Soils Bull. 22, FAO, Rome

Gaikawad, S.T. and Bhaskar, K.S. 1988. Crop production potential in Vertisols and associated soils - A case study. Trans. Intl. Workshop Swell-Shrink Soils, Oxford & IBH, New Delhi, India, pp.226-228

LAND EVALUATION OF AHMEDNAGAR DISTRICT FOR RAINFED AND IRRIGATED AGRICULTURE

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INTRODUCTION

Land evaluation is the process of collating and interpreting basic inventories of soil, vegetation, climate and other aspects of land in order to identify and compare promising land use alternatives in simple socio-economic terms. Different systems of land evaluation such as land capability classification, land suitability classification and soil ratings (parametric approach) are in use. The present study evaluates the soils of Ahmednagar district for growing sorghum and pearl millet under rainfed farming and sugar cane under irrigation, following the FAO Framework for Land Evaluation (1976).

The Study Area

Ahmednagar district has a total area of 1.7 million ha and is situated between 18°15′ to 20°0N latitudes and 73°37′ to 75°35′E longitudes. It is characterised by basaltic tablelands, mesas and buttes with steep escarpments, surrounded by eroded footslopes that merge into a broad alluvial plain. The elevation varies between 500 and 1050m above mean sea level. The climate is semi-arid tropical with average annual rainfall of 560mm, 77 percent of which is received during the monsoon season, and annual potential evapotranspiration of 1583mm. The temperature regime is isohyperthermic, with mean winter soil temperature of 23.5°C and mean summer soil temperature of 27.2°C.

The soil characteristics vary with the relief features of the landscape. Fifteen soil series have been identified in the semi-arid part of the district and mapped as associations at 1:50 000 scale. In Soil Taxonomy, the soils are classified as Lithic Ustorthents, Paralithic Vertic Ustropepts, Vertic Ustropepts, Fluventic Ustropepts, Typic Chromusterts and Udic Chromusterts.

LAND EVALUATION

Land characteristics such as topography (slope %) wetness (drainage), physical soil characteristics (texture, coarse fragments, depth), fertility characteristics (organic carbon, CEC) and salinity and alkalinity (EC, ESP) were evaluated for growing sorghum and pearl millet under rainfed conditions and sugar cane under irrigation by following the 'limitation method' and the 'parametric method' (Sys 1980, 1985; FAO 1985).

Evaluation for Sorghum

On the basis of rating of limiting characteristics, the soils of the Sindudi, Torkewadi, Pargaon and Dadgaon series are marginally suitable for growing sorghum. On the basis of the parametric method these soils are rated as unsuitable. Topography, depth and coarse fragments are the major limitations. The soils of the Wadgaon, Annapur, Umbraj and Dholwad series are moderately suitable. They have topography and/or drainage limitations. Soils of the Sirasgaon, Talegaon, Sawargaon, Nimone and Otur series are rated as suitable for sorghum.

Evaluation for Pearl Millet

Rating of soils indicates that the soils of the Sindudi, Torkewadi, Pargaon and Ukadgaon series are marginally suitable. The soils of the Wadgaon, Annapur, Umbraj and Dholwad series are moderately suitable. The soils of Umbraj series have drainage problems whereas other three soils have limitations of topography and soil physical characteristics. The soils of the Sirasgaon, Talegaon, Sawargaon, Nimone and Otur series are suitable for growing pearl millet.

Evaluation for Sugar Cane under Irrigation

An area of about 1 77 000 ha is under irrigation at present and more is being brought under irrigation for growing sugar cane. Evaluation of the soils to grow sugar cane under irrigation is, therefore, of interest. The suitability evaluation indicates that the soils of the Sindudi, Torkewadi, Pargaon, Wadgaon, Ukadgaon and Umbraj series are unsuitable for irrigation. The soils of the Talegaon series are marginally suitable while those of the Sirasgaon, Sawargaon, Annapur, Nimone, Otur and Dholwad series are moderately suitable for growing sugar cane under irrigation.

REFERENCES

FAO, 1976. *A framework for land evaluation.* Soils Bull. 32, Rome

FAO, 1985. *Guidelines: land evaluation for irrigated agriculture.* Soils Bull. 55, Rome

Sys, C., 1980. *Land characteristics and qualities and methods for rating them.* FAO World Soil Res. Rep. 52, Rome

Sys, C., 1985. *Land evaluation.* Parts I, II and III, Pub. Agricole 7, ITC Univ. Ghent

STEPS FROM SOIL SURVEY AND LAND EVALUATION TO LAND USE PLANNING

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INTRODUCTION

The assessment of the potential performance of land, when used for specified purposes, provides information needed for planning, development and management decisions.

Two studies are reported here that apply and develop the FAO Framework for Land Evaluation (1976). An integrated survey was undertaken in Glen Tanar, in the Scottish Highlands, to evaluate the potential of the area for commercial forestry. Another study was undertaken in the Panchnawari village of Wunna watershed near Nagpur, India, to study land suitability for common rainy season crops, as a basis for finding ways of improving yields on sustained basis.

GLEN TANAR

The catchment of Glen Tanar occupies some 8000 ha of hill country, ranging in elevation between 150 and 1000 m. The bedrock is granite with some quartz mica schists and quartzite but the soil parent materials are glacial drifts deposited by ice moving down-valley and, also, breaching the watershed and bringing some basic rock debris into the catchment.

Figure 1 shows the growing seasons, defined by a soil temperature of 6°C or more. Figure 2 plots accumulated temperature in day/degrees above 6°C at different elevations over the year. Data were calculated from three long term stations in the locality and a fragmentary record from nearby Ben McDhui (1246 m). They do not take account of aspect, which is important at this high latitude, or exposure to strong winds, which increases Precipitation at low elevation averages 840 mm in a year, with 216 rain days, but ranges between 620 and 1300 mm. Precipitation and, also, exposure increase markedly uphill.

It is obvious that land use options are severely limited by the short, cool growing season and severe winters. There is a little arable land on the low ground, areas of planted and natural forest up to 400 m and, elsewhere rough grazing. Therefore, forestry was selected as one of the most promising land use options.

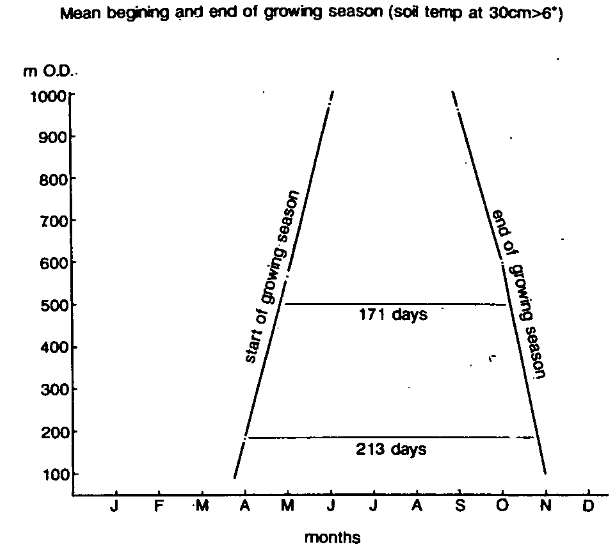


Figure 1. Glen Tanar, growing season

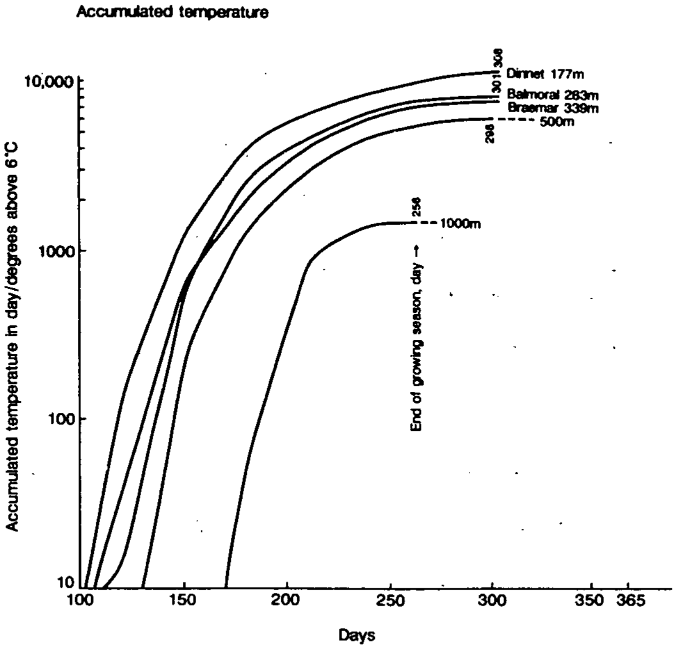


Figure 2. Glen Tanar, accumulated temperature

Survey procedure

Survey began with stereoscopic interpretation of 1:25 000 air photos, identifying landforms and vegetation types and, by interpretation, soil parent materials, drainage classes and provisional soil boundaries. Fieldwork was planned mostly in transects across the grain of the country to check the soils and, also, to gather performance data from existing areas of forest. Collection of tree performance data for 36 sites and fully characterising each site took 10 man days over and above the soil survey work.

Table 1 summarises the soil mapping legend. The diagnostic characteristics were specifically chosen for the purpose in hand - to predict forest performance and costs of establishment and maintenance. Correlation with the FAO Soil Legend (1988) has been added.

Crop performance model

Two techniques were applied to develop a crop performance model (Figure 3): correlation and stepwise multiple regression. For correlation of continuous variables like elevation and tree height, the field data could be used directly. Qualitative data like drainage class, parent material and soil type were grouped into classes and given a subjective ranking. For example soil groups were rated: 1 brown soils, 2 podzols, 3 peaty indurated, 4 gley and peaty gley. Parent materials were rated: 1 mixed lithology till and moraine, 2 granitic till, 3 stony drift, 4 peat. The correlation matrix (Stage 2 in Figure 3) identifies which land characteristics are most closely related to crop performance.

The indices of crop performance: tree height, marketable timber height, yield class (m^3 ha^{-1} yr^{-1}) and yield index (m^3 per tree at mean maximum increment) are most closely correlated with elevation, parent material and soil type. Yield models were then produced by regression for each soil type (Stage 3 in Figure 3). From these models a yield class map was drawn from the soil/topographic base map.

For example, yield class for Scots Pine on cambisols developed on mixed parent materials (mapping units TA be and MA be) is:

$$YC = 12.3 - 0.267 \text{ elevation (m)}$$

Yield class varied from <2 to 12 over the catchment.

Financial analysis

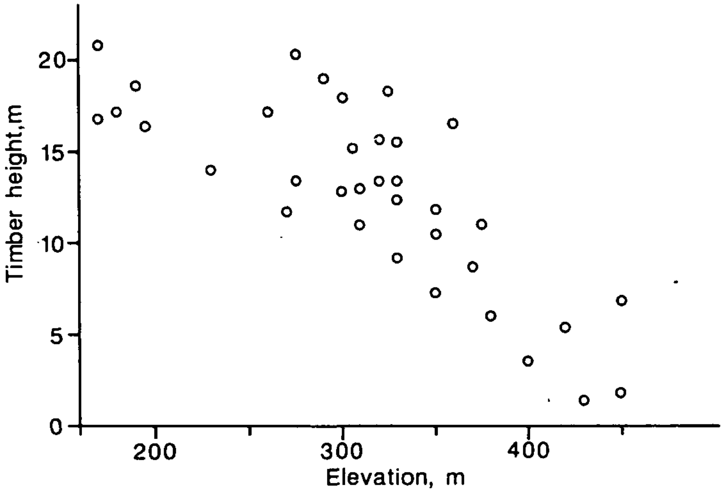
Net present value and internal rate of return were calculated for each yield class under two management options, viz conventional planting and accelerated natural regeneration. Accelerated natural regeneration was found to be most profitable because of the low initial cost. A sensitivity analysis showed that the most important factor in determining financial viability is not

Table 1. Glen Tanar, soil mapping legend

Parent Material physical	lithology	Symbols	Well drained soils: *subarctic*	*brown earth*	*podzol*	Seasonally waterlogged *peaty indurated*	Poorly drained *gley*	Very poorly drained *peaty gley*
				Dystric cambisols	*Haplic podzols*	*Gleyic podzols (histic, placic phase)*	*Dystric gleysols*	*Histic gleysols*
Stony drift (>75% stones)	Schist & quartzite	SS	Phase Skeletic					
	Granite	SG	sa		po			
Scree (> 75% stones)	Undifferentiated	SK						
Lodgement till (<35% stones, compact or indurated subsoil)	Schist & quartzite	TS		be Fungarth	po Strichen	pi Gaerlie	gy Anniegathel	pg Hythie
	Granite	TG		be Raemoir	po Countesswells variant	pi Charr	gy Terryvale	pg Drumlasie
	Mixed, >10% basic igneous	TA		be Tarves	po Tillypronie	pi Pressendye	gy Pitmedden	pg Pettymuck
Morainic drift (>35% stones, not compact)	Mixed, >10% basic igneous	MA		be Tarves variant	po Tillypronie variant			
Cobbles, alluvium and sand	Undifferentiated	AL						
Peat	Organic	PT						

Undifferentiated mapping unit, mixed bottom land MBL
Stony phase (>35% stones and/or >10% rock outcrops) z of TS, TG and TA

Stage 1 Collect key data, example



Stage 2 Statistical analysis

ALL DATA CORRELATION — *correlation coefficient >0.66 is significant at 99% probability level*

	ELEVATION	ASPECT	DEPTH	STONES	PARENT MATERIAL	DRAINAGE	SOIL TYPE
ASPECT	-0.208						
DEPTH	0.215	0.349					
STONES	0.557	0.051	-0.058				
PARENT MAT	0.642	-0.060	0.145	0.541			
DRAINAGE	0.189	0.111	0.327	0.091	0.131		
SOIL TYPE	0.600	-0.166	-0.027	0.471	0.850		
TREE HEIGHT	-0.765	-0.138	-0.124	-0.580	-0.720	-0.763	-0.843
TIMBER HEIGHT	-0.791	-0.127	-0.122	-0.546	-0.691	-0.728	-0.812
YIELD CLASS	-0.698	-0.240	-0.199	-0.527	-0.683	-0.618	-0.724
YIELD INDEX	-0.766	0.032	-0.268	-0.424	-0.736	-0.592	-0.745

Stage 3 Performance model

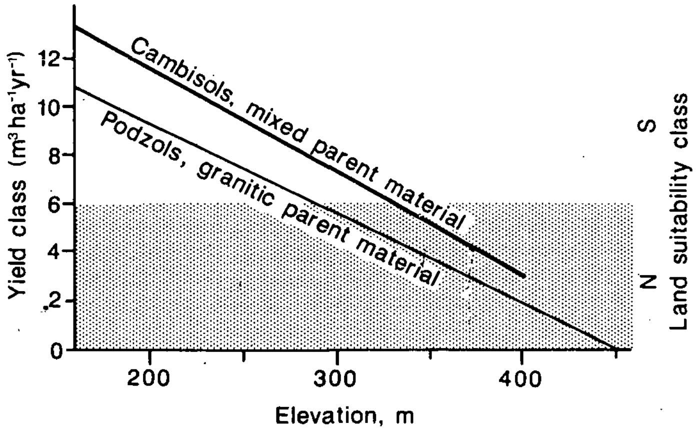


Figure 3. Stages in the development of a crop performance model

productivity but the level of grant available from the government to establish forest. Under present circumstances, a yield class of 6 or above is viable, corresponding to land below 350 m on the best well-drained soils and below 275 m on the poorest well-drained soils. This financial assessment was superimposed on the yield class model of Figure 3, Stage 3.

Management plan

From all this information, a management plan and production cycle were drawn up. Fencing of land against grazing deer is a major expense, so the management units had to be generalised compared with the intricacies of the yield class map to make economic blocks for fencing, and subsequent management and extraction of the crops (Figures 4 and 5).

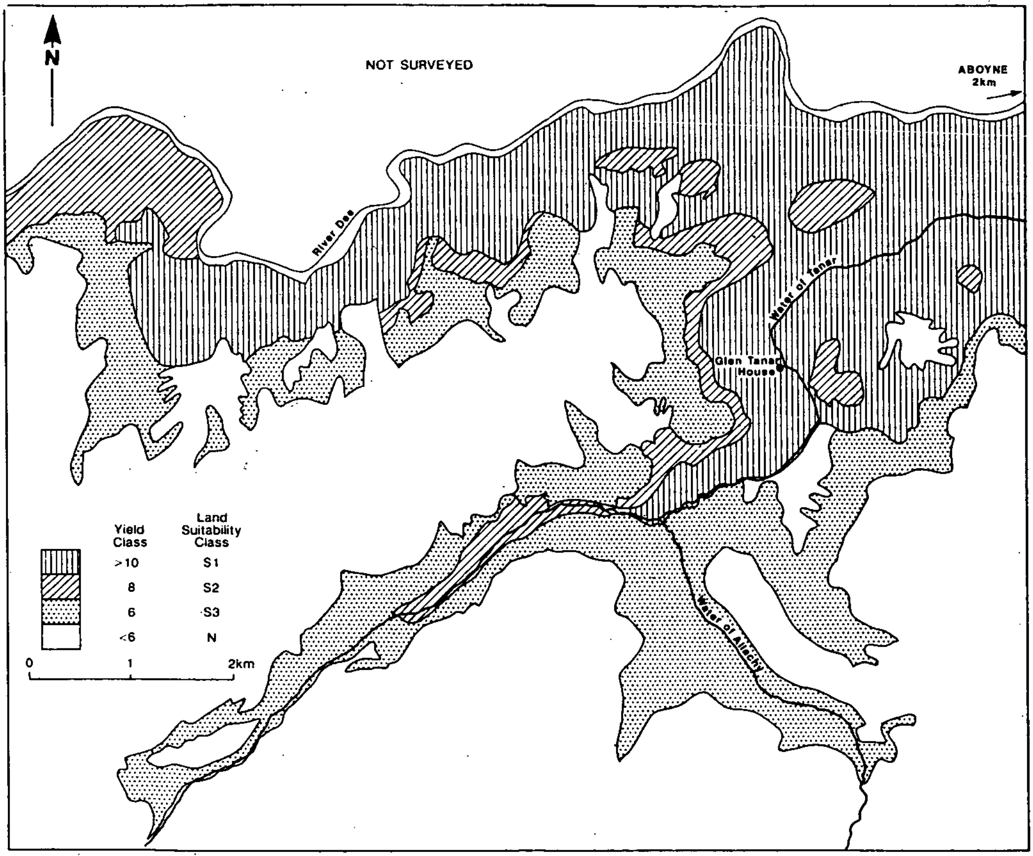


Figure 4. Glen Tanar, predicted yield clases and land suitability classes

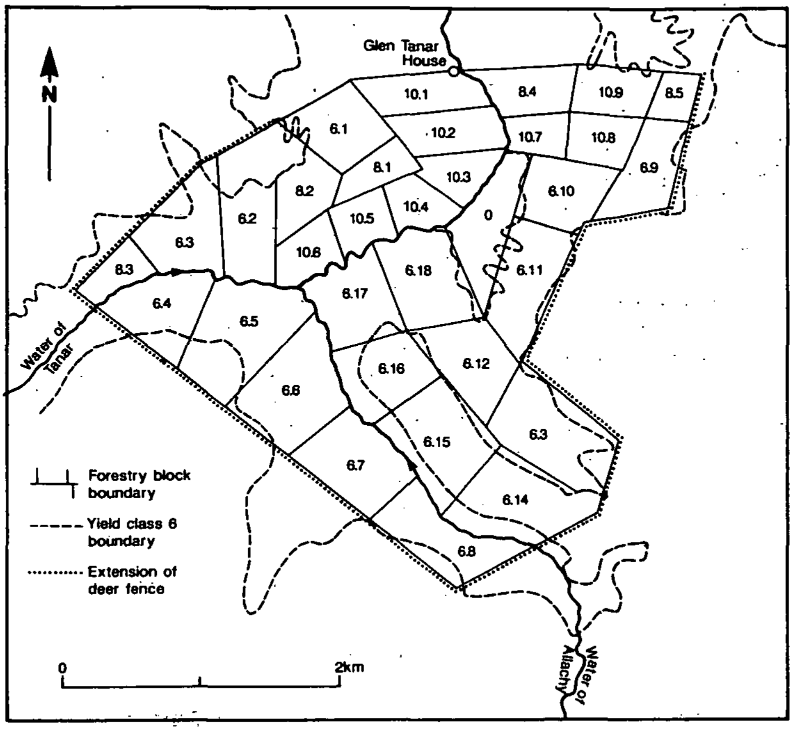


Figure 5. Glen Tanar, forest management blocks

PANCHNAWARI AREA

The Panchnawari area, in the basin of the river Wunna, ranges from 300 to 450 m above mean sea level. The rock is dominantly basalt with sandstone and shale on the northern side. The climate is tropical dry subhumid, with mean annual temperature of 27°C and mean annual rainfall of 1100 mm.

__Survey procedure__

A detailed soil survey was carried out using a 1:4 000 cadastral base. Originally, soils were mapped as series and phases of series but for interpretation of land suitability they were grouped into 5 classes, as summarised in Table 2.

Crop yield data were collected from farmers' fields.

Table 2. Panchnawari: summary of soils and land use (Ingle 1990)

Soil class (Soil Taxonomy, family; all hyperthermic)	Depth, cm	Drainage class	Land use
A. (Typic Chromusterts, very fine, montmorillonitic	> 100	Moderately well drained	Cotton, sorghum, pigeonpea, wheat gram, vegetables
B. (Vertic Ustochrepts, very fine, montmorillonitic	50-100	Moderately well drained	Cotton, sorghum, pigeonpea, citrus
C. (Typic Ustochrepts, clayey-skeletal, mixed)	25-100	Well drained	Cotton, sorghum, pigeonpea, citrus
D. (Lithic Ustorthents, clayey-skeletal, mixed)	<25-50	Well drained	Cotton, sorghum, pigeonpea
E. (Lithic Ustorthents, loamy, mixed)	<25	Well drained	Grazing

Table 3. Panchnawari Soil classes, land suitability sub-classes and crop yields

Soil Class	Land Suitability sub-class			Yield (Kg ha^{-1}) (farmers' practice)		
	Cotton	Sorghum	Pigeonpea	Cotton (PKV-2)	Sorghum (CSH-5)	Pigeonpea (Local)
A	S2s	S1	S2s	860	2750	540
B	S2s	S1	S2s	710	2580	510
C	S3s	S2s	S2s & S3s	590	1760	440
D	S3s	S2s & S3s	S3s	520	1130	300
E	N2s	S3s	N2s	----- current fallow -----		

Land evaluation

Using the FAO Guidelines: land evaluation for rainfed agriculture (1983), each group of s

ils was evaluated in physical terms. Table 3 shows a good correspondence between this evaluation and farmers' yields. The main soil characteristics likely to affect yield are rooting depth, soil texture, graveliness, and drainage class.

Note, however, that the yields under improved management at (Punjabrao Agricultural University, Akola, (PKV 1989) are much higher than those obtained by farmers, as follows:

Cotton 1500 Kg ha^{-1} compared with 8 at best, in farmers fields;
Sorghum 4300 Kg ha^{-1} compared with 2750;
Pigeonpea 1100 Kg ha^{-1} compared with the farmers' best yield of
540 Kg ha^{-1}.

So there is great scope for improvement in the field.

CONCLUSIONS

Soil maps cannot be used directly by land use planners and decision-makers. Some further steps in land evaluation are needed to produce quantitative data on crop performance and, beyond these, financial appraisal of different land use types on different soils. This requires additional field work to collect suitable production data. Simple modelling of crop performance based on statistical analysis of production data, then enables us to extrapolate results from sample areas.

REFERENCES

FAO 1976. *A Framework for Land Evaluation.* Soil Bull. 32, FAO, Rome

FAO 1983. *Guidelines: land evaluation for rainfed agriculture.* Soil Bull. 52, FAO, Rome

FAO 1988. *Soil map of the world, revised legend.* World Soil Resources Report 60, FAO, Rome

Ingle, A.M. (1990). *Land evaluation for agricultural crops in a type area - Wunna watershed,* MSc (Ag) thesis, Punjabrao Krishi Vidyapeeth, Akola, India

PKV (1989). *Krishi Vidyapeeth Dainandini.* Punjabrao Krishi Vidyapeeth, Akola, India

DEVELOPING COARSE CROP MODELS FOR LAND USE PLANNING

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INTRODUCTION

For land use planning, we need to predict the performance of different crop options on each parcel of land. The conventional approach of land evaluation has been comparative: attributes such as soil type and rainfall have been compared directly with some measure of crop performance to derive a productivity rating or land suitability classes, by which different mapping units are ranked, for example Bhaskar et al. (this workshop). Another way is to derive statistical models from observed correlations between measured land attributes and sample measurements of crop performance, for example Sohan Lal and Dent (this workshop). More ambitious, dynamic models have been developed to predict the potential yield of crops beginning with their maximum photosynthetic potential, then progressively reducing this according to the sufficiency of solar energy, water and nutrients (Feddes et al. 1978, Diepen et al. 1981).

Nearly 70 per cent of Indian crops are rainfed. Drought is common both through low rainfall and its erratic distribution. Water stress is the most limiting single factor in the cropping system and is the most difficult to correct. It is also difficult to model because it represents the momentary balance between water demand and water supply, both complex attributes of the land (Figure 1). The demand side can be estimated from meteorological data: the reference evapotranspiration modified by a coefficient specific to each crop and its stage of growth (FAO 1977). To model the supply side we have to integrate rainfall, soil water storage, and the ability of the crop to draw on the stored soil water.

Where soil water is readily available, soil water depletion is the same as demand and there is no water stress. But soil water is not all readily available. The less the soil water, the harder it is to get.

Cook and Dent (1990) found that soil water potential can be used as an index of the rate of supply. Using data for reference evaporation, crop coefficient, rooting depth, soil water release characteristics and unsaturated hydraulic conducitivity, they were able to model soil water potential and, thereby, sufficiency of supply for a wide range of crops on a day-to-day basis.

However, data for soil water release characteristics and unsaturated hydraulic conductivity are lacking for a good number of Indian soils. Therefore, we have developed a coarser model of water sufficiency to avoid some of the gaps in our data. Calculations were made for the main crops in three catchments: Nainwal near Delhi, Wankaner near Vadodara and Saongi near Nagpur.

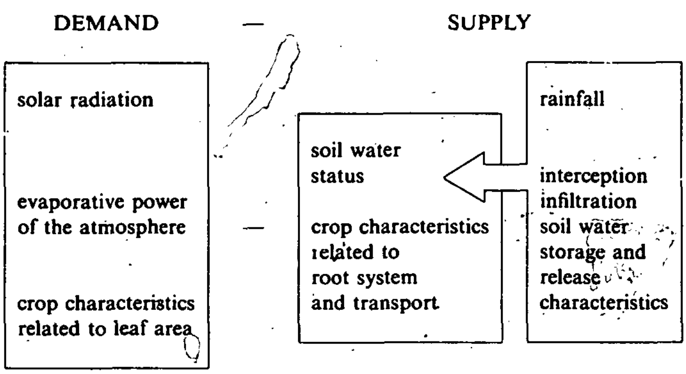


Figure 1. Soil water sufficiency (from Cook and Dent 1990)

METHODS

Crop water demand

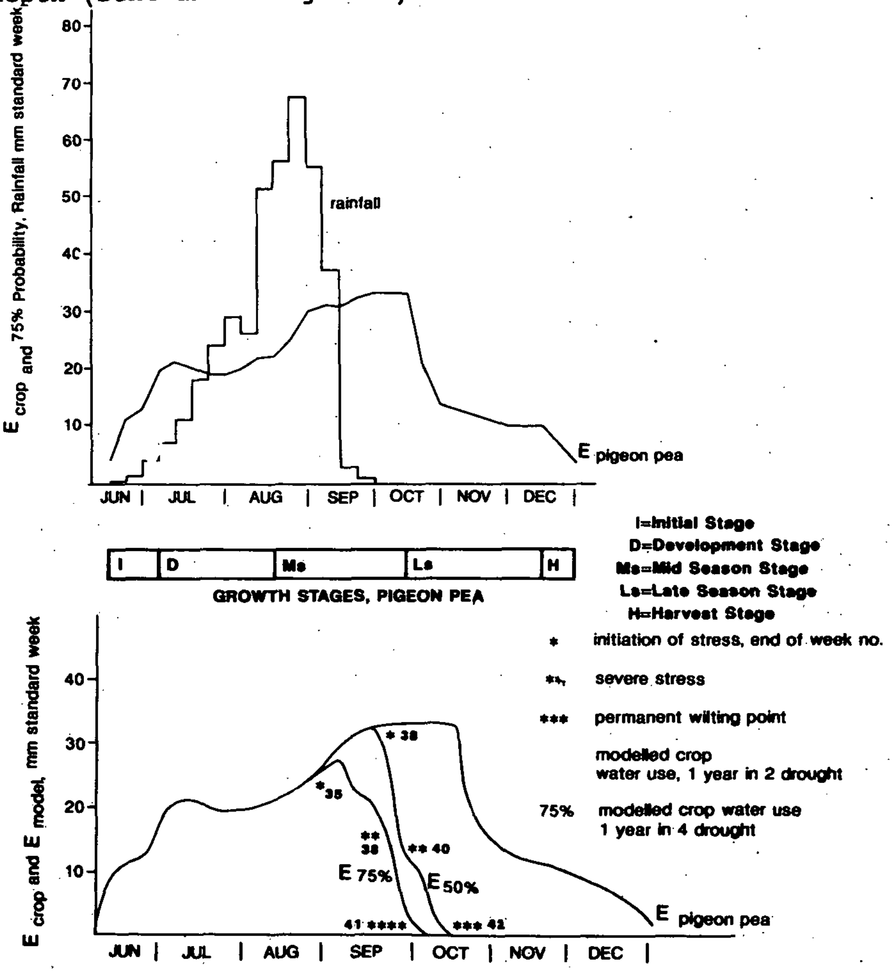
Mean monthly data for reference evapotranspiration, Eo, were converted graphically to standard weeks. Mean weekly crop water demand was then estimated by applying a crop coefficient, Kc, appropriate to the stage of growth; Ecrop = Eo x Kc. Crop coefficients for some crops were taken from FAO (1977, 1979) or were adapted from crops with similar characteristics. Published values apply only to lush crops well supplied with water and nutrients, not for thinly-sown, stressed crops characteristic of droughty areas, so our Ecrop values are too high.

Water supply

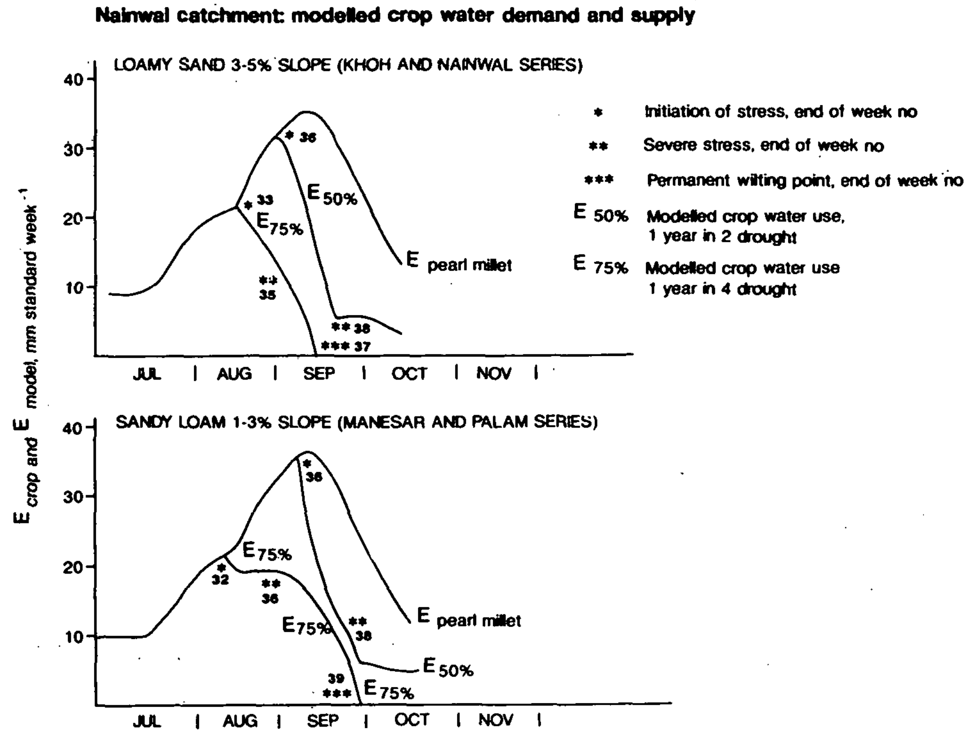
For rainfall, 75 per cent and 50 per cent rainfall exceedence values, representing the one-in-four years and one-in-two years drought, were used. As with evapotranspiration, monthly values were transformed graphically to standard weeks. To estimate effective rainfall, the rainfall was partitioned between runoff (and runon) and infiltration according to rainfall intensity, slope angle, position of the slope, and soil texture. In the absence of real measurements of runoff, somewhat arbitrary judgements were unavoidable.

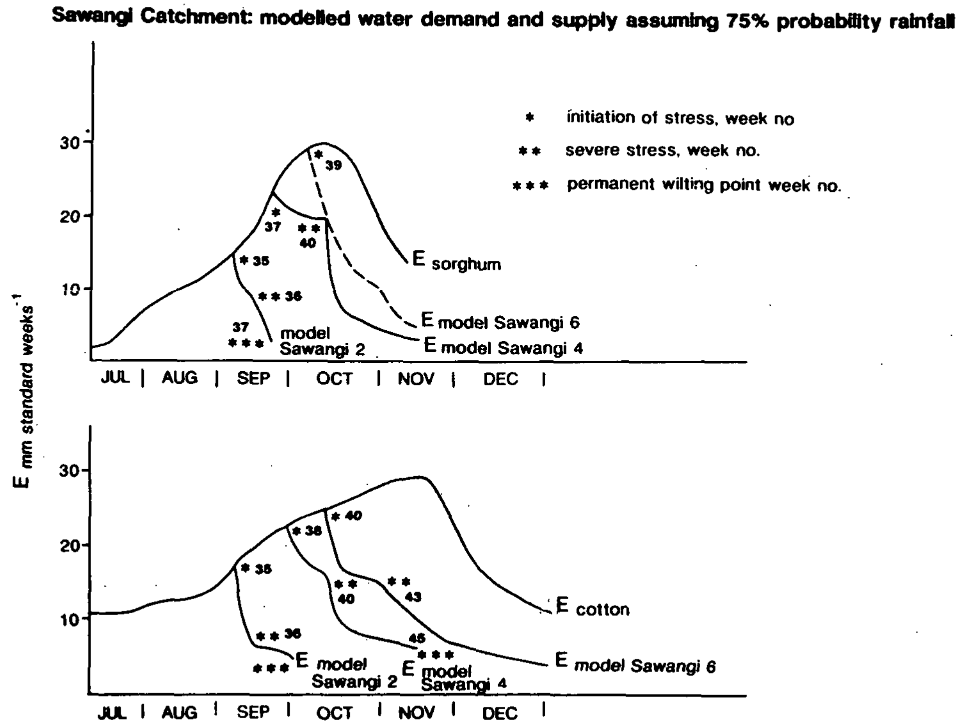
We assumed that, at the end of the long dry season, soil water content has been reduced to permanent wilting point over the whole crop rooting depth. From the beginning of the rains, effective rainfall for each week is added to the soil, layer by layer beginning with the topsoil and crop water demand is taken away. Weekly calculations of gains and losses from the soil water store were performed on a spreadsheet.

Water supply to the crop was estimated from the rooting depth and a crude model of supply was that the first 1/3 of the available water capacity (AWC) is supplied at the full demand rate, of Ecrop, the next 1/3 of AWC is supplied at two-thirds of Ecrop, and the last 1/3 of AWC is supplied at one-third Ecrop. In the absence of measurements AWC was estimated from soil texture and depth (Dent and Young 1981).



Figures 2 and 3. Wankaner catchment, pigeonpea: Ecrop and 75 per cent probability rainfall, modelled crop water use





Figures 4 and 5. Modelled crop water use, Nainwal and Saongi (Sawangi) catchments

RESULTS AND DISCUSSION

Figure 2 shows for the Wankaner catchment Ecrop of pigeonpea compared with 75 per cent probability rainfall. The mismatch is evident. Crop survival and performance depend on the ability of the soil to store and supply water for the later stages of growth. Similar data for tobacco and pearl millet snow that these crops must depend substantially, or entirely, on irrigation.

The modelled water supply for the one-year-in-two and one-year-in-four drought were worked out for pigeonpea and tobacco. on the two most widespread soils in the Wankaner catchment. However, data are given for pigeonpea only (Figure 3) as there was not much difference between the crops. The onset of water stress and permanent wilting point are flagged. Both soils are coarse textured and of low available water capacity, so rainfall has the main influence on water sufficiency. At the higher rainfall, rainfed pigeonpea will survive but at a poor yield level.

The story is the same for the Nainwal catchment (Figure 4). A pearl millet crop is viable at 50 per cent probability rainfall, when the crucial growth stage can be completed, but not at 75 per cent probability.

A different picture emerges from the Saongi catchment where rainfall is greater and more reliable (Figure 5) and there is a broader spectrum of soils. In a shallow Saongi-2 soil, neither cotton nor sorghum can complete their growth cycle in a one-year-in-four drought. On the deep, clayey Saongi-6 soil, both crops come through. On Saongi-4, sorghum completes its growth but cotton, with a longer growing season, suffers stress during the crucial flowering period and cannot complete its cycle.

CONCLUSIONS

The repetitive calculations needed to model soil water sufficiency are laborious but can be translated easily into a computer program. New data can then be incorporated and answers to specific questions produced on demand. At present, we lack real data on field capacity and water release characteristics; runoff and infiltration rates in relation to soil type and slope; hydraulic conductivity; crop rooting patterns in different soils; rainfall and evaporation probabilities on a ten day or weekly basis; and crop coefficients appropriate to the rainfed crops of India. But even our coarse model is useful in highlighting the onset and severity of water stress over a wide range of crops and soils and can serve as a starting point for soil scientists and agronomists to design viable cropping rainfed systems.

Obviously, modelling a land quality like sufficiency of water is only a step towards crop performance modelling. The next step is to scale the water sufficiency model in terms of crop yield. A coarse but useful assessment could be made by retrospective analysis of trials data.

REFERENCES

Cook, H.G. and Dent, D.L. 1990. Modelling soil water supply to crops. *Catena* 17:25-39

Dent, D.L. and Young, A. 1981. Soil Survey and Land Evaluation. Geo Allen & Unwin, London

Diepen, C.A. Van, Rappoldt, C., Wolf, I.J. and Van Keulen, H. 1981. *CWFS Crop Growth Simulation Model WOFOST*. Centre for World Food Studies, Wageningen, The Netherlands

FAO, 1977. *Crop Water Requirements*. Irrigation and drainage paper 24, Rome

FAO, 1979. *Yield response to water*. Irrigation and drainage paper 33, Rome

LAND CLASSIFICATION FOR SUSTAINABLE USE

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INTRODUCTION

Land capability classification was developed in the 1930's by the Soil Conservation Service of the United States Department of Agriculture. It was intended to help farmers to allocate their land to the most profitable use consistent with containing soil erosion. The original land capability classification places land into one of 7 classes according to the severity of physical limitations that restrict the range of crops that can be grown and/or make necessary increasingly costly soil conservation measures.

The procedure and the product are both straightforward. Probably, this accounts for the popularity of the system amongst soil survey organisations and users of survey information (Woode 1981). Sometimes, as in India, land capability classification has been adopted uncritically, without developing and testing criteria that are appropriate to local soils and farming systems. Sometimes it has been used for purposes for which it was not designed and for which it is not appropriate, simply because it is the ready-made product. In this paper, we are advocating 'made-to-measure' soil survey interpretations, rather than offering the customer a product 'off-the-peg'. Of course, these made-to-measure interpretations should be tested in the field and the criteria for allocating classes must remain provisional until they are.

There are many circumstances where a straightforward, 'one-shot' classification of land is wanted. For example, where a national overview is needed as a basis for developing government policy and targeting resources to combat land degradation. In this case, soil erosion is only one of the hazards so the original land capability classification is not appropriate. Policy makers are asking: 'What are the hazards of degradation?' 'Where are the areas at risk?' 'How severe is the problem?' 'What technical steps are needed to arrest or reverse this land degradation in different areas?

Here we put forward, for testing, a soil survey interpretation that answers these questions. We have used the well-tried principles of land capability classification (Klingebiel and Montgomery 1961) but, to make clear that the end product will sometimes be different, we suggest the name Land Classification for Sustainable Use.

Sustainable use is a kind of land use that does not progressively degrade the land but is capable of maintaining its productivity indefinitely. Obviously, to be sustainable from the present users' point of view the land use in question must also be economically viable.

CLASSIFICATION FOR SUSTAINABLE USE

A three tier grouping of soil mapping units is proposed. At the highest level, **sustainability classes** indicate the severity of the hazard which, in effect, limits the range of land uses that are sustainable; **subclasses** indicate the nature of the main hazard or limitation to use; and at the third level **management units** group soils that need similar management practices to sustain productive land use. We think it is important that policy-makers be given information at the level of management units, so that appropriate kinds of management are promoted and so that the level of investment needed can be calculated.

Suitability classes

Class I: A wide range of crops possible without special management practices.

Class II: A wide range of crops possible with careful but cost-effective management practices.

Class III: Only limited range of arable crops possible and special management practices are needed to contain hazards. Forest or pasture are sustainable with careful but cost-effective practices. Not suitable for arable crops.

Class IV: Pastures or forest is sustainable under special management.

Class V: Sustainable management options limited to recreation, wildlife and conservation forestry.

Subclasses and criteria

Provisional criteria for four subclasses are suggested, covering limitations to sustainable use and economic viability. We have considered four kinds of limitation or hazard: drought, soil erosion, flooding and salinity/sodicity.

Drought hazard (d): is the deficiency of available soil water (a combination of evaporative demand, rainfall and soil water storage (Giri et al, this workshop)) causing crop failure or reduction of yield. Drought classes are equated with management response in the absence of irrigation and are ultimately reflected in adaptable cropping systems (Table 1).

Table 1. Proposed drought classes assessed for different cropping systems

Class	Degree of hazard	Warm wet season	Cool dry season
I	Nil	All climatically adapted successfully	crops can be grown
IId	Slight	Wide choice of rainfed crops	Limited choice of rainfed crops
IIId	Moderate (crop failure once in 5 years)	Limited choice of rain-fed crops	Crop production practicable by adopting dryland farming techniques
IVd	Severe crop failure once in 2 years)	Very limited choice of rainfed crops	No reliable crop on stored moisture
Vd	Very severe (frequent crop failure)	Limited to range and forest	

<u>Erosion hazard</u> (e): takes into account slope angle, soil permeability and stability.

Class I: Slope angle <1°

Class IIe: Slope angle 1-2° on unstable soils (for example, Vertisols) and 2-4° on stable soils

Class IIIe: Slope angle 2-4° on unstable soils and 4-8° on stable soils

Class IVe: Slope angle 8-10° on stable, permeable soils only. Mechanical conservation measures such as graded bench terraces for arable crops, perennial high plant cover like forest or well-managed pastures with well maintained graded bunds and protected waterways required.

Class Ve: Slope angle >4° in unstable soils

<u>Flooding</u> (f): Flood recurrence, duration and depth of inundation are taken as criteria to define different classes of flood hazards as given below:

Class I: Nil, no flooding risk

Class IIf: Slight flooding once in 10 years, <2 days and <15 cm depth

Class IIIf: Moderate flooding once in 5 years, 2 days to 1 week, 15 to 25 cm depth

Class IVf:	Severe flooding at least once in a year, 1 week to 4 weeks, 25-50 cm depth
Class Vf:	Very severe flooding every year, longer than 4 weeks, >50 cm depth

<u>Salinity and sodicity:</u> ECe is taken as an index of soil salinity. Five different classes with ECe in dS m^{-1} given in parentheses are slight (<4), moderate (4-8), strong (8-15), very strong (15-25), and severe (25-50). Sodicity is expressed as the exchangeable sodium percentage (ESP). Sodicity classes, as produced by Sehgal et al. (1987), are: no hazard (<10), slight (10-15), moderate (15-25), strong (25-40) and severe (>40). Probably, it will be necessary to adjust these according to clay mineralogy: montmorillantic soils remain permeable and workable at higher ESP values than kaolinitic soils.

<u>Management requirements</u>

It will be easiest to specify special management for sustainable use at the management unit level where detailed soil information can be used. However, this is only possible where there are detailed soil maps. Where this is not the case, it will be necessary to provide guidance and the subclass level. As an example, Table 2 lists the kinds of management appropriate to erosion hazard subclasses.

Table 2. Management requirement for sustainable use in subclasses limited by erosion hazard

Subclass	Management requirements
I	Maintain maximum crop cover and organic matter status
IIe	Cultivation and cropping on the contour; grass strips or live hedges on the contour; less than 50 percent of the rotation with low-cover crops
IIIe	As IIe but with less than 30 percent of the rotation under low crop cover; well-designed and well-maintained physical soil conservation structures or agroforestry systems
IVe	Perennial crops with good ground cover; or well-managed forest; or well-managed pasture with good cover and supplementary physical conservation structures, especially protected waterways; or well-maintained bench terraces
Ve	Conservation forestry or natural habitat with minimum ground disturbance and well-managed wildlife.

CASE STUDY

The proposed land classification for sustainable use was applied to three catchments, viz. Nainwal (NBSSLUP, 1982), Saongi, and

Wankaner (Sharma. et al. 1983) situated within different agroclimatic zones. Results for Saongi are presented here as an illustration. The catchment encompasses widely-differing textures (loamy sand to clay), depth (very shallow to very deep) and drainage class (excessively drained to moderately well drained) occurring on different landforms. Soils have been grouped into sustainable land use classes II to IV based on soil characteristics and climate. At catchment level, the classification pinpoints the sites that require soil and water conservation measures for sustained use and the residual drought hazard that can be overcome only with irrigation. At this scale, management units and subclasses are identical. This would not be the case if the interpretation were made at national or state level where classification to subclass level would involve a very great simplification of the standard soil map.

Table 3. Saongi catchment soils - their characteristics and classification for sustainable land use

Soil series and landform	Main soil characteristics	Drought hazard subclass	Erosion hazard subclass	Flooding hazard subclass	Classification for sustainable use
Saongi-1 (Hill, 10-15° slope	Very shallow (<20cm), loamy sand, low AWC, well drained	V	V	I	Vde
Saongi-2 (Foothill, 3.5° slope)	Shallow (20-30cm), gravelly sandy clay loam, low AWC, well drained	IV	IV	I	IVde
Saongi-3 (Foothill, 3-5° slope)	Shallow (25-50cm), gravelly sandy clay loam, low AWC well drained	III	IV	I	IVe
Saongi-4 (Foothill, 3-5° slope)	Dleep (50-90cm), clay loam, high AWC, well drained	III	III	I	IIIde
Saongi-5 (Bottomland, 3-5° slope)	Very deep (100-150cm), silty clay loam, high AWC, modertely well drained	II	II	I	IIde
Saongi-6 (Bottomland, 1-3° slope)	Very deep, silty clay, high AWC, moderately well drained	II	I	II	IIdf

AWC: Available water capacity

REFERENCES

Klingebiel, A.A. and Montgomery, P.M. 1961. *Land capability Classification*. Agric. Handb. 210. U.S. Dept. Agric., Washington, D.C., U.S.A.

NBSSLUP, 1982. *Soil Survey and Land Evaluation of Maneser, Nainwal, Sairowan and Khoh Villages of Gurgaon District, Haryana*. ICAR Report 444, NBSSLUP, Nagpur, India

Sehgal, J.L., Saxena, R.K. and Vadivelu, S.V. 1987. *Field Manual* - Soil resource mapping of different states in India. NBSSLUP, Nagpur, India

Snarma, R.C., Patel, A.K., Patel, H.C. and Giri, J.D. 1983. Land Evaluation and Detailed Soil Survey of Wankaner Watershed, Savli Taluk, Baroda District, Gujarat. Report 1, Baroda Regional Centre, NBSSLUP, India

Woode, P.R. 1981. 'We don't want soil maps - just give us land capability'. The role of land capability surveys in Zambia. *Soil Survey and Land Evaluation 1*, 1, 2-5

AGRONOMICAL ASPECTS OF CATCHMENT MANAGEMENT A CASE STUDY AT KHAPRI, NEAR NAGPUR

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INTRODUCTION

Watershed degradation threatens the livelihoods of rural people and constrains their ability to develop a healthy agricultural base. Poor product vity of the land, in general, leads to inappropriate cultivation practices and use of marginal lands for agriculture. Consequently, soil erosion is increased and productivity of land is reduced (FAO 1982).

Costly engineering measures to reduce the soil-water loss are not widely practicable but simple agronomical measures may be adopted since these are economically acceptable; they do not involve a big outlay or take up land for engineering structures; and farmers can understand, learn and adopt them easily (Stannet 1988).

Catchment (or watershed) management involves the planning and implementation of proper land use practices to mitigate the loss of natural resources and productivity, and increase the efficiency of land, and water use. Keeping the above in view, studies at Khapri catchment were undertaken for evaluation of soils, and adoption of agronomic measures to minimise soil and water loss and to increase production on sustainable basis. The goal has been to generate and evaluate soil-based agrotechnology and to develop a model that can be transferred to similar physiographic, soil and agroclimate conditions elsewhere.

Agronomic aspects were based on research, field demonstrations and adoption of practices by the farmers, as suggested by Sheng (1987) and Stannet (1988).

Khapri Catchment

Khapri catchment, a part of Khapri village, covers 122 ha by the Nagpur-Amravati road, 57 km from Nagpur. The average altitude of area is around 580 m above mean sea level with hillocks up to 610 m. It lies in the upper catchment of Kar river, a tributary of the Jam river. The climate is subtropical - subhumid with average rainfall of 1127 mm, mean annual air temperature of 26.9°C, mean monthly maximum and minimum temperatures of 42.8°C (in May) and 12.1°C (in December). The temperature regime is hyperthermic, the moisture regime ustic. Table 1 summarises the physiography and soils.

Table 1: Khapri catchment physiography, soil mapping units and soil characteristics

Physiographic unit	Mapped Soil unit	Soil characteristics and classification	Area (ha)
Hillslope	Kp-2(c)	Shallow, sandy loam, moderately sloping, severely eroded, slightly rocky. Paralithic Ustorthent	11
Foothill	Kp-6	Extremely shallow, sandy clay, gently to moderately sloping, moderately eroded, moderately stony. Lithic Ustorthent	12
Tableland	Kp-2(a)	Shallow, clayey, gently sloping, moderately eroded, slightly stony. Paralithic Haplustalf	2
Upper Plain	Kp-1	Shallow, clay loam, gently sloping, moderately eroded. Lithic Ustorthent	26
	Kp-3	Moderately shallow, sandy clay, calcareous, gently sloping, moderately eroded. Typic Ustochrept	15
	Kp-4	Shallow, clay, calcareous, gently sloping, moderately eroded. Typic Ustochrept	11
Scarp Slope	Kp-2(b)	Shallow, sandy clay loam, moderately sloping, severely eroded, slightly rocky. Paralithic Ustorthent	7
Lower Plain	Kp-5	Deep, clay, calcareous nearly level to very gently sloping, none to slight erosion. Typic Chromustert	2
Valley Bottom	Kp-7	Moderately shallow, clay, calcareous, gently sloping, moderately eroded. Typic Ustochrept	15

Vegetation and land use

The hills are covered with forest species mainly of teak, *Tectona grandis*, tendu, *Disovoes melanoxylon* and anjan, *Hardwikia binnate*. Foothills and tablelands are occupied by bushes of ber, *Zizyphus jujuba*, palas, *Butea monosperma*, and *Acacia species*. *Lantana*, *Saccharum*, *Zizyphus*, sandlewood and grasses are the major vegetation types covering the escarpments, while valley slopes and the valley bottom are under cultivation. The major season crops are sorghum, cotton, pigeonpea, groundnut, soybean, cowpea, greengram, blackgram and sesame. During the winter season, gram, wheat and vegetables are grown under protective/assured irrigation. Orange cultivation is prominent near water sources and in valleys.

CROP CULTIVATION PRACTICES

The following aspects of crop production systems are important from the watershed management point of view.

Sound cropping systems: Suitability to soil type(s) based on growing period adaptability, needs and economic output could be recommended for sound cropping systems. Growing period is the key characteristic, based on available moisture. Optimum soil-crop suitability linkages have been found as below.:

Soil Units	*Growing Period*	*Suitable Crops*
Kp-1, Kp-2(b), Kp-6	70 to 90 days	Greengram, blackgram, soybean
Kp-2(a), Kp-2(c)	90 to 100 days	Greengram/blackgram, and cowpea mixed with hybrid sorghum
Kp-2(a), KLp-3	110 to 130 days	Groundnut, soybean, hybrid sorghum (followed by linseed/gram during winter
Kp-7	130 to 150 days	Sorghum, early maturing pidgeon-pea and cotton, groundnut and soybean followed by gram

Crop management: The selection of a suitable package of practices, including plant genotypes, tillage and cultural practices, fertiliser doses and, even, plant protection measures, should differ according to slope, texture, erodibility and length of operational fields. To obtain more crop canopy and dry matter (vis-a-vis yield) the impact of levels of management has been found very effective.

It is observed that sorghum and pigeonpea in strip cropping have significant effect in reducing the runoff and sedimentation loss. As per growing period in different soils, early-maturing rainy-season pulses (greengram and blackgram) and medium-maturing crops (groundnut and soybean) could be grown in narrow and wide strips, respectively.

In contour farming, every furrow acts as small terrace which holds water and gives more time for water absorption into the soil by intercepting the water flow. The fields bunds and perennial grass lining provide strong support against the force of water flow. Agroforestry species could be grow along the TCM supplemented with silvipasture.

RESULTS

Crops like sorghum and pigeonpea are essentially grown by the farmers to meet domestic needs. To reduce the erosion effect and obtain better economical return, mixed cropping of pulses has been found to be useful. (Table 2).

Table 2. Crop yields and economic gains from various crop combinations

Crop(s)	Yield (q ha^{-1})				Net Profit (Rs ha^{-1})			
	Sole Crop	Mixed Crop 1	Mixed Crop 2	Total	Sole Crop	Mixed Crop 1	Mixed Crop 2	Total
1. Sorghum	28.4	----	----	28.4	2256	----	----	2256
2. Sorghum + Greengram (3:1 seed mixing)	----	24.1	2.8	26.9	----	2172	1680	3852
3. Sorghum + Greengram (4:4 rows)	----	19.8	4.3	24.1	----	1800	2064	3864
4. Sorghum + Blackgram (3:1 seed mixing)	----	22.6	3.8	26.4	----	2034	2280	4314
5. Pigeonpea	13.6	----	----	13.6	5440	----	----	5440
6. Groundnut	15.2	----	----	15.2	4560	----	----	4560
7. Pigeonpea + Groundnut	----	8.1	6.3	14.4	----	3240	2260	5500

Crop residues, stubble and cowdung are useful for composting and manuring in the fields. Turning into soil the dropped foliage of early-maturing pulses provides green manuring which improves the physical condition of soil and adds nutrients. The water holding capacity of the soil is also improved. Due to smothering effect of dropped foliage, early field preparation and sowing of winter crops saves the pre-sowing and pregermination irrigation.

Sowing of crops across the slope: Flat sowing followed by earthing with a blade harrow and sowing of seeds in the ridge-side helps in interculture, topdressing and conservation of soil and water. Due to absorption of water in-situ, the moisture supply and growing period is increased which results in a more assured crop harvest.

Methods of soil and water conservation appear to be economically attractive. From experience at Khapri, we can more on to recommending the technology for effective land resource management at the micro-watershed level.

ACKNOWLEDGEMENTS

The suggestions and guidelines given by Dr J.F. Meiman, Dr Freeman Smith and Dr T. Sheng of ISFNR (CSU), Fort Collins, USA are acknowledged gratefully.

REFERENCES

FAO, 1982. *Watershed Management in Asia and Pacific: problems, needs, status of programmes and strategy for foster upland conservation in the region*. DP/RAS/81/053 Technical Report, FAO, Rome

Stannet, H.R. 1988. *Agronomic Conservation Measures*. Watershed Rehabilitation short course, Oct. 31- Nov. 4, Department of interior, CSU, Fort Collins, USA.

Sheng, T.C. 1987. *Project formulation and evaluation of watershed*. Lecture notes, Course-510, CSU, Fort Collins, USA.

EVALUATION OF VARIOUS WATER CONSERVATION MEASURES FOR MANAGEMENT OF AGRICULTURAL WATERSHEDS

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INTRODUCTION

It is always a challenge to a watershed manager to decide what is the best treatment for a particular watershed. Soil bunds are being substituted by the vegetative bunds of vetivera grass which is cheaper and easy to manage, can be used under variety of field situations, and allows more opportune time for infiltration of water in the field (Greenfield 1987). Graded bunding is costly, and difficult to maintain in swelling clays. This paper reports work on evaluation of contour sowing along with vetivera key-lines compared with graded bunding and with conventional across- the-slope sowing under sole and intercropping systems.

MATERIALS AND METHODS

Field trials with split plot design were carried out during 1989-90 at the Boregaon-Manju watershed under the Land Resource Management project of the Punjabrao Krishi Vidyapeeth, Akola. The soil of the experimental site is a member of the fine, montmorillonitic, hyperthermic family of Typic Ustorthents. Bulk density was 1.3 g cm^{-3} and the hydraulic conductivity 160 mm day^{-1}. Soil water content at -30 kPa and -1500 kPa was 37.9 and 24.8 percent, respectively. The slope was 1.5 percent.

Main treatments consisted of 1) sowing across the slope; 2) sowing parallel to graded bunds (0.2 percent grade at 1 m vertical interval); and 3) sowing along the contour with vetivera key-lines (0.5 m vertical interval). Subtreatments consisted of sorghum (CSH 5), cotton (AHH 468), greengram (kopergaon), sorghum + greengram (2:1), and cotton + greengram (1:1). Gross and net plot size were 100 x 10 m and 98.2 x 8.8 m, respectively. Water use and water use efficiency were estimated as proposed by Khera and Sandhu (1988).

RESULTS AND DISCUSSION

Crop yield response

Yields under different treatments are given in Table 1. A significant crop yield response was recorded for contour sowing with vetivera key-lines compared with graded bunding and especially compared with across the slope sowings. This might be due to uniform distribution of surface water leading to uniform recharge of the effective rooting depth. Also, vegetative bunds act as barriers for sediment and runoff. Overall, infiltration rate, moisture storage in soil, and recharge of the stored moisture during the moisture deficit period are increased. Similar results have been reported by others (Mishra et al. 1979, Dhruvanarayana 1983, Anonymous 1990).

Table 1. Productivity (q ha^{-1}) as influenced by various treatments

Treatment (sowing)	Sorghum	Cotton	Greengram	Sorghum + Greengram	Cotton + Greengram	Mean
Across the slope	17.81	4.86	1.97	23.43	5.83	10.78
Along the contour	24.82	5.53	3.22	30.67	9.00	14.61
Along the graded bund	21.66	5.05	2.45	24.86	7.49	12.30
Mean	21.36	5.15	2.55	26.32	7.44	

	SE +	C.D. 5%
Mean treatments	0.37	1.44
Subtreatment	0.30	0.87
Interaction effect	0.52	1.51

A significant increase in total productivity by 23.2 and 44.5 percent was achieved by intercropping of sorghum + greengram and cotton + greengram over sole sorghum and cotton, respectively. Interaction effect of moisture conservation and cropping system treatments was also significant.

Water use and water use efficiency

Maximum water use was observed under contour sowing, followed by graded bunding and across the slope sowing (Table 2). Amongst the crops studied, cotton had highest water requirement followed by sorghum and greengram, indicating that the water requirements of crops is mainly a function of the duration of crops.

Table 2. Total moisture use, mm, (and moisture use efficiency, kg ha^{-1} mm)

Treatment (sowing)	Sorghum	Cotton	Greengram	Sorghum + Greengram	Cotton + Greengram	Mean
Across the slope	295 (6.0)	387 (1.3)	254 (.0.8)	331 (7.1)	391 (1.5)	332 (3.3)
Along the contour	295 (8.3)	393 (1.4)	257 (1.3)	334 (9.2)	389 (2.3)	334 (4.5)
Along the graded bund	294 (7.4)	385 (1.3)	249 (1.00)	325 (7.7)	385 (1.9)	327 (3.9)
Mean	294 (7.3)	388 (1.3)	253 (1.0)	330 (8.0)	388 (1.9)	

The highest moisture use efficiency was recorded for contour sowing along with live bunding, indicating higher yield per millimetre of water. Similar results were also reported by Atarsingh and Bains (1971). Water use efficiency was comparatively higher under intercropping of sorghum + greengram and cotton + greengram over sole sorghum and cotton, respectively.

Water use during growing season

Water use during 15 to 39 per cent growing season of cotton and cotton + greengram was higher than the earlier and later periods; more than 50 per cent of total moisture use was during this period (Table 3).

Table 3. Moisture use, mm, by cotton and cotton + greengram as a function of percent growing season

Treatment (sowing)	Crop	Period (percent growing season)				
		Up to 15	15-39	39-63	63-100	100
Across the slope	Cotton	49	207	65	66	387
Along the contour	Cotton	53	202	68	69	392
Along the graded bund	Cotton	54	201	63	68	395
Across the slope	Cotton + Greengram	50	207	65	69	391
Along the graded bund	Cotton + Greengram	47	201	68	70	385

For sorghum and for sorghum + greengram, use was maximum during 23 to 61 percent growing season, and it was 57 to 62 percent of total moisture use of the crops (Table 4). Differences in water use were slight under various water conservation treatments during a particular growing season period, except that sorghum + greengram had higher moisture use over sole sorghum for the 23-61 percent growing season period.

CONCLUSIONS

A maximum and significant increase in total productivity to the extent of 18.8 and 35.6 percent was recorded due to contour sowing with vetivera key-lines over sowing along the graded bunds and across the slope, respectively. The highest water use was during the growing season period of 15-39 percent in case of cotton and cotton + greengram, and during the period of 23-61 percent in case of sorghum and sorghum + greengram.

Table 4. Water use, mm, by sorghum + greengram as a function of percent growing season

Treatment (sowing)	Crop	Period (percent growing season)			
		Up to 23	23-61	61-100	100
Across the slope	Sorghum	54	168	73	295
Along the contour	Sorghum	55	168	73	296
Along the graded bund	Sorghum	54	169	71	294
Across the slope	Sorghum + Greengram	55	201	75	331
Along the contour	Sorghum + Greengram	59	202	74	334
Along the graded bund	Sorghum + Greengram	50	204	71	325

REFERENCES

Anonymous, 1990. *A report of research work done on Manoli watershed development project 1989-90.* Punjabrao Krishi Vidyapeeth, Akola, India, pp. 8-12

Dhruvanarayana, V. V. 1983. Effective use of environment-soil erosion. *Dryland Agril. Res. in India*, pp. 113-119

Greenfield, J. C. 1987. *Vetivera grass* *Vetivera zizanioides* - *A method of vegetative soil and moisture conservation.* Bull. World Bank, New Delhi

Khera, R. L. and Sandhu, B. S. 1988. Soil water flux and field water balance as influenced by irrigation regime for sugarcane on a sandy loam soil. *J. Indian Soc. Soil Sci.* 36:1-8

Mishra, D. K., Ram Prasad and Suraj Bhan, 1979. Impact of soil conservation practices on crop production in *India. J. Soil Water Conserv.*, 17:52-57

COMPUTERISED SOIL DATABASE MANAGEMENT

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INTRODUCTION

Good quality data are an essential asset to a soil survey organisation and can be used many times for research and practical applications. However, they can also be a liability; the greater the quantity, the bigger is the liability unless managed efficiently. Many soil surveys throughout the world have reached or passed the point where they can manage all their data efficiently by traditional methods. Consequently they have been forced to introduce computer data handling (database management) whether they wanted to or not. NBSSLUP is no exception to this trend, and, thanks to help from ODNRI and the British Council, is now in a much better position to store, manage and retrieve some of the data it holds.

One of the mandates of NBSSLUP is to collect information and store it as databases for soil and land resource planning of the country. In a period of 30 years the Bureau (and its previous section within the AISUS) has collected a wealth of data in the form of reports, tables and, most importantly, as soil maps.

SOIL SURVEY DATA

Soil data include:

- **Point data,** data at a given point, eg. profile descriptions, horizon analyses;

- **Areal data,** also known as spatial data, mostly in the form of maps together with detailed legend and mapping unit descriptions.

Point data are managed by a Database Management System (DBMS) but spatial data are stored and organised within a geographical information system (GIS). The recent availability of GIS on personal computers has given soil survey organisations the facility to overlay several maps simultaneously (eg. soil, geology, land use and to produce thematic maps in a fraction of the time it took when such operations had to be done manually by cartographers.

Information held by a soil survey organisation exists in many forms - in notebooks as free text, in abbreviated style on proformas, as tables and, more recently, as organised files on a computer. Generally it is factual data which are used for classification, interpretation or statistical manipulation at the time of the survey, at its conclusion, or long after field work has been completed.

COMPUTER APPLICATIONS

The fundamental expectations from database management on a computer are: firstly the facility to store large quantities of information securely and, secondly (and of prime importance), is the ability to interrogate and retrieve data using a DBMS. Properly structured and programmed databases can provide a 'user friendly' means of access. They also enable regular retrievals or operations which would never be contemplated (due to the time required) if they had to be done manually.

Computers have streamlined the process of data management in all branches of knowledge. Recent developments in computer graphics applications and GIS have brought about a revolution in many professions, including soil surveys. Experience of this was acquired by the two senior authors during a training program at the Soil Survey and Land Research Centre (SSLRC) at Silsoe. The SSLRC Land Information System (LandIS) is mounted on a multi-user DEC VAX 11-750 with terminals on campus and remote access on Ministry for Agriculture staff via the British Telecom data network. In addition to soil data from the field and laboratory, LandIS contains land use, geological and climatic information for England and Wales. It is being used for soil survey information storage and retrieval, for crop modelling and quantified land evaluation procedures.

Geographical Information System

Geographical Information Systems are computer software programs that store spatial data (in digital format) with capabilities of transformation and output of spatial and statistical information. Geographic data can be stored in computers in three formats, viz. vector, raster and quadtree. The SPANS software used by NBSSLUP has capabilities for using all three formats. The configuration of the GIS workstation is as follows:

Elonex 386S with 80MB Hard Disk
1*1.44MB (3 ½") and 1*1.2MB (5 ¼") FD Drives
NEC MULTISYNC-3D MONITOR
VGA Card
B/W Monitor
GTCO DIGITISER with 16 BUTTON CURSOR
PRINTER - NEC PINWRITER P7 PLUS
1 x Epson 1050 printer
1 x X-Y A3 plotter
Software: SPANS ver. 4.3, DBASE IV, FOXBASE 2.0

One of the major applications of GIS lies in preparing thematic maps from the soil survey data. The results of an experiment to prepare such maps from the soil map of area covered by Survey of India toposheet number 41I (on 1:250 000 scale) are presented here.

SOIL MAPPING UNITS GUJ41I

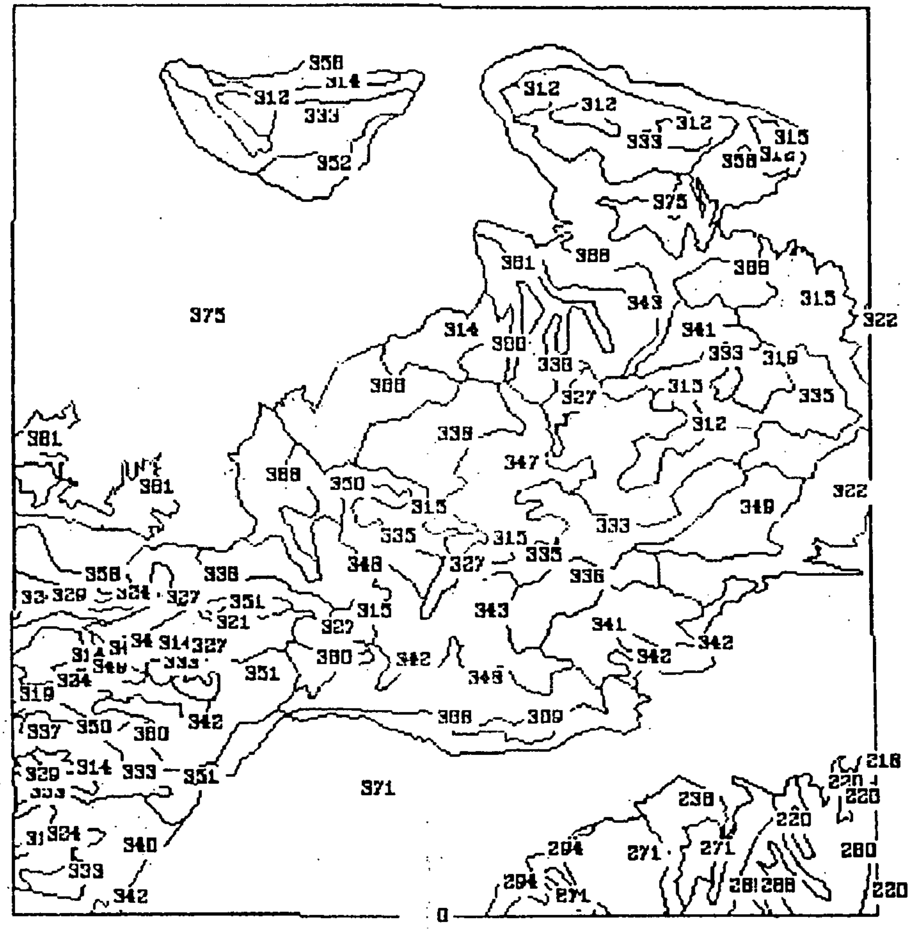


Fig.1

A copy of the soil map of sheet 41I was digitised using the SPANS module TYDIG, and the mapping unit numbers were assigned as the feature codes for the centroids of every mapping unit polygon. The result of this operation was a 'vector' file of lines, nodes and labels (Fig. 1). As SPANS is a raster-based system (images somewhat similar to those on a television screen) the vector file had then to be transformed into many 'pixels' (small rectangles) in quadtree format, ie. some pixels small, some of medium size and, where there is uniform soil, some large pixels.

For this study, the digitised map was exported to SPANS with topology and a new *Universe GUJ41I* was created for map storage and manipulations. The vector file (.vec) and the header file (.veh) were copied into this universe after making necessary modifications in the header file. Polyconic projection with ellipsoid 10 was chosen for this study and frame was set keeping the need for title and legend in view. A vector and, subsequently, a Quadded map was created in this universe with a quad level of 12. The latter determines the accuracy of the polygon boundaries and can be calculated.

Twelve characteristics of the dominant soils of the polygons were considered, viz. soil depth, calcareous classes, reaction classes (pH), drainage classes, particle-size classes, soil parent material, soil salinity, sodicity, erosion classes, soil flooding classes, slope classes, mineralogy classes and soil taxonomic unit. As the latter is not a numeric field, reclassification was carried out and the map produced was from the reclassified (.RCL) file. Attribute files (.TBA) were created from the SPANS menu and checked and edited in the universe directory.

The original soil map was then subjected to overlay modelling, after creating an EQUATION.INP file in the universe GUJ41I for use in preparing the various thematic maps and the maps for the twelve themes mentioned above were prepared and printed. Examples are shown in monochrome in Figure 2.

CONCLUSIONS

The training programme at Silsoe for the two senior authors was effective in as much as there is now confidence within the Bureau to use the immense amount of data collected at 10 km grid interval as point data files for integration within the SPANS system. Application programs like ISIS.PRG have already been written using dBASE III and IV for data entry operations and storage for future utilisation.

The task of storing the vast amount of information in the form of soil maps has already been initiated. Initially, only the dominant soils of the units have been considered for making thematic maps. Plans for SPANS are in hand to include the subdominant soils and also inclusions so that better results can be achieved.

SLOPE MAP GUJRAT-411

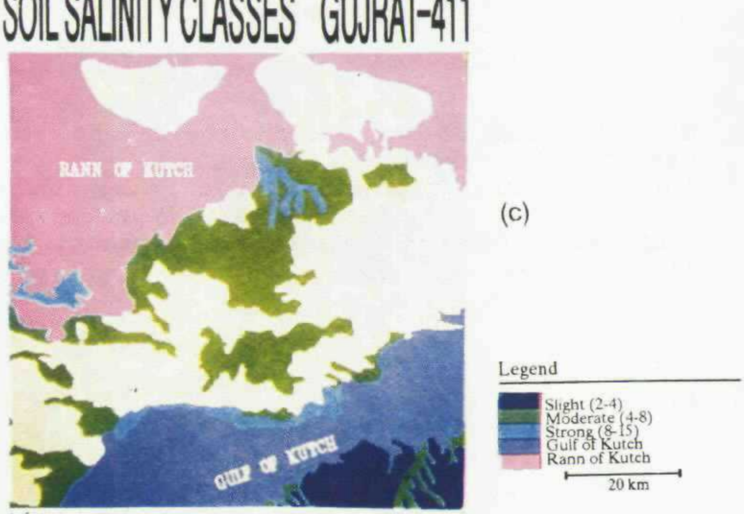
(a)

SOIL DEPTH CLASSES GUJRAT-411

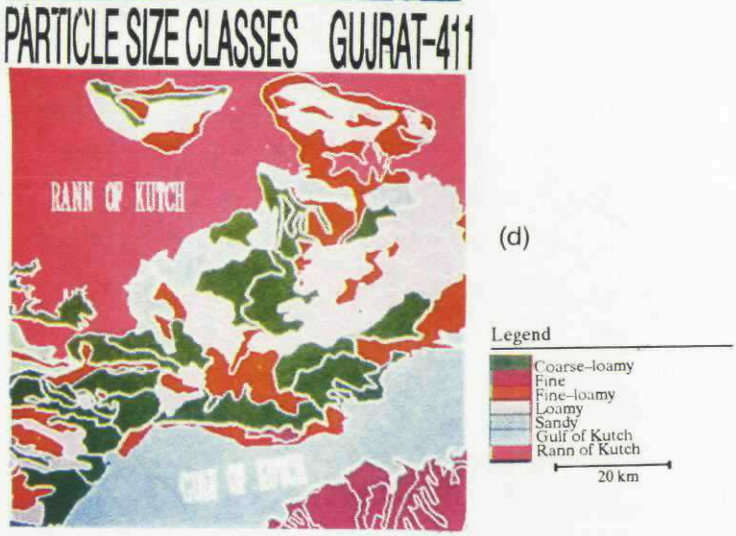
(b)

SOIL PARENT

Figure 2 a, b, c, d, e Example
(origi



(c)



(d)

(e)

atic maps produced by SPANS
n colour)

The creation of an Indian equivalent to the SSLRC National Catalogue of Soils (NATCAT) would be very beneficial - especially for soil series rationalisation. Over the past few years, small leaflets for certain soil series have been published, but a computer database of similar information would be much more useful.

ACKNOWLEDGEMENT

The authors are grateful to Dr J.P. Sharma and Mr S.R. Singh for supplying the sheet 41I for digitisation and Mr S. Srinivas for help in digitisation and processing of data.

ALES MICROCOMPUTER-BASED FRAMEWORK FOR LAND EVALUATION

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INTRODUCTION

Land evaluation using the FAO 'Framework for land evaluation (1976) makes use of independent as well as interdependent data pertaining to soil, climate and socio-economic aspects. This process is time-consuming and error-prone as repetitive calculations and reference to many tables have to be made. Early attempts to automate the procedure (Young and Goldsmith 1977, Wood and Dent 1983) had certain limitations for universal application (Van Wambeke and Rossiter 1989). The Automated Land Evaluation System (ALES) developed by Rossiter and Van Wambeke (1988) is illustrated with an example from the Singhik watershed from Sikkim, India.

MATERIALS AND METHODS

The ALES program

'ALES' is a computer program that acts as a 'framework' for land evaluation. It does not contain any fixed evaluation criteria but allows the evaluator to build his own 'expert system' to compute the physical and economic suitability of the land mapping units (LMUs). It has six components consisting of a 'knowledge base' for describing the land utilisation types (LUTs), a 'database' for describing the lands to be evaluated, an 'inference mechanism' to relate these two for computing the suitability of the LMUs for a LUT, an 'explanation' facility to know the cause of interpretation, a 'consult' mode to give access to consult the model, and a 'report generator'. ALES runs of IBM or its compatibles.

Model building

The evaluator builds a preliminary version of the model by selecting a few LUTs, expressing them in terms of their most important land use requirements (LURs), determining the basis of evaluation by choosing the land characteristics (LCs), constructing decision procedures to relate these LCs to LURs and determining the prices and interest rates. After building the preliminary model, the evaluator selects the LCs data of the map units for entering them into the database and computing the evaluation. The evaluation matrices show five kinds of rating for each map unit for each LUT. These are (a) physical suitability subclass, (b) economic suitability classes, (c) predicted gross margin, (d) expected yield, and (e) rating for single land qualities (Rossiter 1990).

ALES knowledge base

A knowledge base is a structured representation of the facts and inferences needed to arrive at decisions. These inferences are expressed as decision trees that are hierarchical multiway keys in which the 'leaves' are the result (eg. severity level of the land qualities), and 'interior modes' are decision criteria (eg. LCs values). This allows both model builder and user to understand the reasoning of the logic of the decision. The decision trees grow exponentially. To avoid complexities, the program allows the use of parametric and limiting yield factors and maximum limitation method for physical suitability. Proportional yield factors that numerically reduce the yield due to limitations are used for economic evaluation.

S1-yield

The S1-yield is the base for computing the predicted yield in evaluation studies. It is the maximum yield expected under optimum condition within the context of the LUTs and evaluation area. It is assumed that the land qualities that affect yield have no limitation or lowest level of limitation. It is not the biological maximum but rather a realistically attainable yield.

Land utilisation types

The five LUTs proposed for the terraced, hilly Singhik watershed of Sikkim are:

Name of LUT	Output	S1-yield unit ha^{-1}	Price Rs. $unit^{-1}$
Citrus plantation (ctr)	Citrus	20,000 nos	0.4
Green ear-corn & paddy	Ear-corn	10,000 nos	0.5
cultivation (hmp)	Paddy	35 qts	100.0
Maize cultivation (maz)	Maize	25 qts	200.0
Paddy cultivation (rpd)	Paddy	35 qts	100.0

Input

The inputs to a LUT (one time and/or annual) are the things required to implement it, regardless of the land on which it is implemented. It depends on the severity level of a specific LUR.

The inputs used for computing economic suitability for the above LUTs in this study are:

Input name	Price Rs. $unit^{-1}$	Input name	Aprox. price Rs. $unit^{-1}$
Citrus plant	2.5/number	Organic manure	20.0/cartload
Potash fertilizer	2.5/kg	Manual labour	15.0/day
Limestone dust	50.0/qts	Maize seeds	6.5/kg
Nitrogen fertilizer	1.5/kg	Pest control	75.0/time
Phosphate fertilizer	2.5/kg	Hired ploughing	25.0/day
Paddy seeds	2.0/kg		

Decision trees

The severity levels of the LURs have been determined in this study by using 43 decision trees. An example of the 'proportional yield decision tree' for LUT-rpd (water availability) is shown below:

I. No limitation > nrc (nutrient retention capacity)

1. High ...... 1.0 2. Medium 0.85
3. Low ...... 0.65 4. Very low 0.00

II. Slight stress nrc

1. High ...... 0.9 2. Medium 0.75
3. Low ...... 0.55 4. Very low 0.00

III. Moderate stress > nrc

1. High ...... 0.85 2. Medium 0.75
3. Low ...... 0.5 4. Very low 0.00

This indicates that when water availability poses 'no limitations' and the nrc is 'high' the yield is expected to be 1.0 and with increasing limitations, yield is reduced as indicated.

Brief description of the study area

The Singhik Watershed of Sikkim, measuring about 460 ha, is located between latitudes 27°33'15" to 27°36'15" N and longitudes 88°37'15" to 88°39'15" E at an elevation of 1150 to 1400 m above mean sea level. It has slopes of 15 to 50 percent. The annual rainfall is about 3250 mm and mean annual maximum and minimum temperatures are 19.9°C and 11.4°C, respectively. Part of the area is well terraced. Relevant physical and chemical properties of the soils of the land mapping units are given in Table 1.

Table 1. Properties of the soils of the LMUs

LMU	Soil depth class	Surface texture	pH 1:2.5 H_2O	Org. C. %	CEC (Cmol kg^{-1})	BS %	Fertility status*		
							Av-N	Av-P	Av-K
TmG2	vd	c	4.5	5.9	8.8	53	h	l	m
TeH3	vd	l	4.5	5.9	8.8	52	h	l	m
ReH3	vd	l	4.9	1.0	9.6	58	l	m	l
RhG2	vd	cl	4.9	1.0	9.7	58	l	m	l
RMhH3	d	cl	4.6	3.7	8.8	54	h	l	m
RMiH3	d	scl	4.6	33.7	8.8	54	h	l	m
SiF2	vd	scl	4.6	5.8	17.6	57	h	m	l
THhG2	md	cl	4.9	2.8	17.5	53	m	m	m

Notations used as per Soil Survey Manual (AIS&LUS 1970)

* Fertility status: h - high, m - medium, l - low

RESULTS AND DISCUSSION

A 'knowledge base' describing the proposed land uses in terms of both physical requirements and economic inputs and a database describing the characteristics of LMUs occurring in the Singhik Watershed of Sikkim (NBSSLUP 1988) were fed into the ALES framework. The economic suitability classes (ESCs) were computed, based on predicted gross margin (which in turn depends on predicted cost of inputs and predicted return from output). The gross margin values were compared with economic class limits predefined to the model for ascertaining the ESCs which are depicted in Table 2.

Table 2. Economic suitability classes of different LUTs

LMU	Land utilisation type			
	rpd	hmp	ctr	maz
TmG2	S1	S2	S3	S3
TeH3	S3	N1	S3	N1
ReH3	S3	S3	N1	N1
RhG2	N1	N1	S2	S3
RMhH3	S2	LS2	S3	S2
RMiH3	S3	S2	S3	S2
RMiH3	S3	S2	S3	S2
SiF2	S1	S2	S2	S2
THhG2	S2	S2	N1	S3

It is evident from the study that the same LMU shows different economic suitability classes for different LUTs and a particular LUT is not equally suitable for all LMUs.

CONCLUSIONS

The ALES software allows fast processing of land data to appraise map units for a set of alternative uses. Once the knowledge base is constructed, it can be applied to other units of the same conditions. The software can cope with compound map units (associations), and crop rotations and enables repeat evaluations under different economic conditions, such as changing prices, interest rates and benefit requirements. The report generator produces printout on inputs, outputs and suitability classes. It contains a mechanism to refine the models which are the core of the evaluation. The modest hardware requirements of ALES make the software a very effective tool for land evaluation.

ACKNOWLEDGEMENT

The first author is grateful to FAO/UNDP for providing financial help and to Dr A. Van Wambeke, and Dr P. G. Rossiter of the Department of Agronomy, Cornell University, Ithaca, U.S.A. for their constant encouragement during the course of study.

REFERENCES

AIS&LUS 1970. *Soil Survey Manual.* Indian Agricultural Researcn Institute, New Delhi

FAO 1976. *A Framework for Land Evaluation.* Soils Bull. 32, FAO, Rome

NBSSLUP 1988. Detailed Soil Survey of Singhik Sub-watershed, North District, Sikkim. Report No. ICAR-517, National Bureau of Soil Survey and Land Use Planning, Nagpur

Rossiter, D.G. 1990. ALES: A framework for land evaluation using microcomputer. *Soil Use and Management* 6;7-20

Rossiter, D.G. and Van Wambeke, A. 1988. ALES software, copy-righted, Cornell University, Ithaca, U.S.A.

Van Wambeke, A. and Rossiter, D.G. 1989. A new approach to computer aided land evaluation. In *Proc. Intl. Workshop Multipurpose Use of Soil Survey Information*, Nairobi

Wood, S.R. and Dent, F.J. 1983. LECS: *A land evaluation computer system*, AGOF/INS/78/006/Manual 5 (Methodology) and 6 (User's Manual). Govt. of Indonesia, Boror, Indonesia.

Young, A. and Goldsmith, P.F. 1977. Soil survey and land evaluation in developing countries: a case study in Malawi. Geo. J. 143:407-438

USE OF MICROCOMPUTER-ASSISTED INFORMATION RETRIEVAL SYSTEM AT THE NATIONAL BUREAU OF SOIL SURVEY AND LAND USE PLANING

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INTRODUCTION

The Documentation Centre was established at the NBSSLUP in order to obtain all relevant scientific and technical information pertaining to soil survey programmes and related aspects. The main approach for information handling, storage and dissemination has been through manually-produced author, title and classified catalogues. These present library collection including all kinds of material is about 5000. Since 1980, to keep the scientists up-to-date, the Documentation Centre has produced the monthly Current Awareness Bulletin covering, so far, 12 000 bibliographic references. Also, the twice-yearly Soil Survey Newsletter has been produced as well as lists of serial holdings, soil survey reports and institute publications.

COMPUTERISED INFORMATION SERVICE

There were many reasons for developing computer applications for information storage and retrieval. Without it, users have to search manually through catalogues and indexes of bibliographic references. The existing catalogues and indexes do not have sufficient access points. As a result, retrieval of information has been very time-consuming. A review of the present position and future needs (Reilly 1987) resulted in the decision to acquire a micro-computer and develop a centralised bibliographic database at the NBSSLUP and, possibly, on-line access to external databases. Accordingly, the senior author undertook training on various aspects of agricultural information services, latest techniques in information handling, on-line access to external databases, the CAIRS system, and design of an NBSSLUP database.

MICRO-COMPUTER-ASSISTED INFORMATION RETRIEVAL SYSTEM

The hardware installed comprises an: IBM PS/2 Model 60, 44MB Computer, DOS 3.30 with a PS/2 Model 55SX Monochrome display, a Proprinter XL24E, and high density 1.44 MB Floppy Diskettes.

The micro-computer Assisted Information Retrieval Systems (MCAIRS) is a powerful and flexible system with a proven track record. It consists of a MicroCAIRS C Application Software, ID : R+4/040889, a versatile software system designed specially for information storage and retrieval. The programs have been written in RTL2, a high level computer language. It is designed by professional information scientists at the Leatherhead Food Research Association, U.K.

ISSSLUP DATABASES

The MCAIRS software system is being utilised for developing the following three ISSSLUP databases, keeping in view the immediate library requirements:

- ISSSLUP Address Database — Library (0)
- ISSSLUP Bibliographic Database — Library (1)
- ISSSLUP Serials Database — Library (3).

Bibliographic database

This is a major database consisting of 20 fields running into 5 screen definition pages, as shown in Table 1. As per users' discretion, each field may be indexed individually and by one or several of the available methods. Those used in this database are the automatic indexing, the full field indexing, the manual indexing and the tagged indexing. The indexing vocabulary is either a free or a controlled one. At present, free vocabulary is being used.

Table 1. Record structure of ISSSLUP bibliographic database

Screen Pages (VDU)	Field Numbers on screens	syn. file	Fields	Window size x no. of windows	Syn.	T.I.	T.S.
Page 1		1	Accession number	7 x 1	acc	--	--
	02	2	Security code	15 x 1	acc	--	--
	03	3	File code	6 x 1	fil	F	--
	04	4	Library Acc. number & entry date	14 x 1	led	F	--
	05	5	Number of copies	1 x 1	cop	--	--
	06	6	UDC no.	54 x 1	udc	T	--
	07	7	Location	54 x 2	loc	A	;
	08	8	Date (public.)	4 x 1	dat	F	--
	09	9	Author(s)	214 x 2	aut	A	;
Page 2	02	10	Title	294 x 3	til	T	--
	03	11	Reference	214 x 2	ref	T	--
Page 3	02	12	Author address	294 x 2	add	--	--
	03	13	Publisher	214 x 2	pub	T	--
Page 4	02	14	Collation	214 x 2	col	T	--
	03	15	ISBN	54 x 1	isb	T	--
	04	16	Language text	54 x 2	lat	A	;
	05	17	DOC type	54 x 1	doc	A	;
	06	18	Bull. no.	7 x1	bno	F	--
	07	19	Bull. headings	54 x 3	buh	--	--
Page 5		20	Descriptors		des	M	

A - Automatic, F - Full Field, M - Manual, T - Gagged, Syn - Synonyms, T.I. - Type of indexing, T.S. - Terminator set

Data entry and basic searching

The data input is first made on data input sheets, taking into consideration cataloguing and indexing details, and then transferred to the respective screen pages, including manual keyword pages. The inverted file can be searched using the tasks SINV or FIND.

Production of bulletins

The main function of the database, apart from producing listings from the inverted file search, is to bring out the monthly bulletin. The maiden computerised monthly Current Awareness Bulletin was issued in May 1990.

Current status and future plans

At present, data input into the system is being carried out besides producing monthly bulletins. It is hoped to complete the data entry of about 17 000 items during the next 2-3 years.

It is envisaged that as soon as the regional centres have PC's and develop their database covering items of regional interest, the exchange of information with the central database will be taken up through periodically-updated floppy diskettes.

A wide range of databases, eg. AGRICOLA, AGRIS, CABI Abstracts, and TROPAG, is available commercially on various host systems. It is proposed to explore on-line access to these databases.

As a short-term measure, until we go into on-line, we could avail facilities associated with CD-ROM technology. This is worth exploring in supplementing the ISSSLUP database.

CONCLUSIONS

Use of MCAIRS software in developing ISSSLUP database could provide a rapid, accurate and cost effective access to the information held in the Documentation Centre. The plans, if carried through, will provide access to the world literature pertaining to NBSSLUP research activities.

REFERENCE

Reilly, P.M. 1987. *Assessment of library information services and recommendations for development.* Report of a visit to NBSSLUP, Nagpur, India. ODNRI, Chatham, U.K

CONCLUSIONS OF WORKING GROUPS

WORKING GROUP I: NATURAL RESOURCE MAPPING

Chairman: Dr J.L. Sehgal

1) Soil resource mapping at 1:250 000 is being carried out to identify different soils and their extent, and to locate areas of development potential and specific management problems. Based on the soil resource maps of different states, priority areas should be demarcated for regional planning. The next step is to prepare 1:50 000 maps for different agro-ecological zones with special reference to degraded lands and areas of high potential.

   Regarding the areas to be ameliorated for increasing agricultural productivity, the areas at greatest economic benefits will accrue from protecting risk of degradation rather than land that is already degraded.

2) Monitoring degraded lands: Large areas are being reclaimed and some other areas are being degraded due to injudicious irrigation, rise of the groundwater, increase of sea ingress water, etc. Remote sensing techniques, used in conjunction with the GIS, should be used to monitor land degradation. For this work, suitable criteria need to be developed.

3) Thematic Maps, for example on erosion, salinity and crop suitability are being generated to create awareness amongst the administrators and user agencies regarding the problems a rent areas. This work should continue. In addition, the area vulnerable to landslides should be identified and mapped for environmental conservation.

4) Mine spoils: Suitable technology is needed to identify the magnitude of this problem for proper land restoration. The role of soil survey staff will be crucial in this regard.

5) Trained staff are needed. for all the above work. It is recommended that morepeople should receive specialist training, both within the country and abroad.

WORKING GROUP II: LAND EVALUATION

Chairman: Dr D.L. Dent

1) Consultations should be initiated between NBSSLUP and other land use planning agencies to explore and develop the applications of the soil survey data base. There are important applications for urban and industrial developments and environmental management as well as in the agricultural and forestry sectors.

2) Systematic yield data, economic and other management data are needed for all the soil survey interpretations. At present, many of these interpretations are speculative.

3) Land use planning is for people, not soil. A stronger socio-economic component should be built into the evaluation of natural resources. Information is needed on current and alternative farming systems, their land resource needs and constraints, so that these can be matched with the resources available.

4) Land capability is a robust concept and land capability classification has a place in farm and catchment level planning. However, criteria and limiting values appropriate to the physical and economic conditions of the different regions of India should be established.

5) Land evaluation is not the same thing as land use planning. It is a step in a sequence beginning with identification of goals and specific land use problems, continuing with the evaluation of land for a range of alternative uses, and going on to monitor the outcome of the decision to change. It is unlikely that any estabished method of land evaluation will serve all purposes, so NBSS and LUP must maintain a strong research capacity to meet changing needs.

WORKING GROUP III: INFORMATION SYSTEMS

Chairman: Dr Peter Bullock

Computing is here to stay and NBSSLUP, with its relåtively early start in this area, is in a good position to lead the developing countries. In terms of setting up a Land Information System, the equipment currently at NBSSLUP is sufficient for needs in the next one or two years. It will then need to be expanded. The training has gone well and there is now a nucleus capable of developing GIS. The recommendations of the Group are as follows:

1) Because of the disparate use of computers by many groups: land planners, librarians, cartographers, etc., there is a need for a clear

coordination of computer activities.

2) Emphasis should be given to preparation of thematic maps and applications of soil maps. There is a need for modelling expertise and it may be useful to have people trained in this area.

3) It would be useful to examine the value for district planners of thematic maps based on 1:50 000 mapping. This would entail taking a district adjacent to Nagpur, for which there is 1:50 000 map and for which there is a strong body of associated data.

4) For continued use of SPANS at Nagpur, there is a need for a high resolution colour graphics board which would enable use of more than 15 colours at one time on a thematic map.

5) Each Regional Centre should be equipped with the PC's and software relating to the soil correlation program, the assessment of land suitability, and productivity models. There should also be standardisation of data input, storage and retrieval.

6) There should be links between the library at Nagpur and those at the Regional Centres and exchange of floppy diskettes etc., should take place. Further, it would be a great advantage to purchase CAB database holdings on CD ROM for providing bibliographies.

7) The possibility of taking SPANS-derived maps and putting them through the chromalin process should be investigated. High quality presentation of our data is essential.

WORKING GROUP IV: WATERSHED MANAGEMENT

Chairman: Dr S. T. Gaikawad

It is necessary to have inventories of climate, soil, water, vegetation and socio-economic conditions of the watershed. This will give us initial status regarding crop, milk, fuel, and fodder production. The results of the survey will be useful to create awareness and to involve people in the programme. The following components have been identified:

a) Through above-mentioned surveys it will be possible to identify the problems and, then, decide the priorities with respect to (i) physiographic information - contour mapping to prepare conservation plan, (ii) mechanical measures, biological measures including field crops and horticulture system, pastures and trees cf suitable species, (iii) studies on integrated nutrient management, (iv) development of cropping system based on soil and land capability classes and management level, and (v) know the effect of land use changes on quality and quantity of runoff.

b) Need for soil moisture studies on different physiographic units and land use.

c) Demonstrations, which should be as comprehensive as possible.

The requirements for such a programme are: (i) developments should be economically viable, technically sound and socially acceptable to suit a specific area, (ii) to have trained manpower for research and training at Regional Centres and SAU's, (iii) the need of proper instrumentation, and infrastructural facilities including field lab., meteorology and working structures, and transport, (v) provision of enough funds, and (vi) periodic assessment of the activities.

FINAL RECOMMENDATIONS

A Working Group for each Technical Session was set up to draw conclusions and make recommendations. The final recommendations covering various themes of the Workshop are given below under three sub-heads, viz. scientific aspects, interactions, and technical support.

Scientific Aspects

- It is important that thematic maps be prepared now for at least some States for which 1:250 000 maps are completed. These will demonstrate the usefulness of soil resource maps for addressing national and regional development issues.

- The 1:250 000 mapping program should be supported by 1:50 000 mapping on a selective basis, to provide more local information on areas of high potential and areas with particular problems.

- Along with development of specific land suitability and other thematic maps, land capability classification should continue as a standard soil survey interpretation but criteria applicable to local conditions should be established.

- Economic and social factors should be built into every stage of land evaluation. It is particularly important to incorporate these into assessments of suitability at farm and village level.

- The techniques of Geographical Information Systems should be developed to integrate the many different types of information needs in land use planning.

- The quality and consistency of the data collected still need to be improved by systematic targeting, definition and quantification of important variables eg. soil depth, run-off, erosion.

- The focus of survey should be land, of which soil is one important facet.

Interactions

Now that a useful base of physical data will be available with the production of the 1:250 000 soil maps, working relationships should be set up with policy-makers and institutions working in related fields so that the information is put to good use. These should include government departments, universities, and farming advisers. Making and maintaining these linkages is just as important as gathering more information for without them the information will not be used.

Technical support

- Methods of data storage and retrieval should be standardised within NBSS and LUP.
- Every Regional Centre should be equipped with a PC for linking with the GIS and the Nagpur main library.
- Maps from SPANS should be put through the Chromalin process to improve their professional appearance for selected cases where the Bureau is interacting with professional users. The range of colours on the maps derived from SPANS should be extended from the present level.