Soil-Site Suitability Evaluation for Cotton

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Abstract : *Cotton is widely (7 m ha) grown in swell-shrink soils of India. However, no proper consideration is given to soil and site properties of these soils (Vertisols and their associates). The average yield of the crop is very low. Soil and site properties such as climate, depth, $CaCO_3$ content, texture, structure, drainage, etc., and their limitation for cultivation of cotton is described by computing linear and quadratic function models. It indicated that the rainfall about 1000 mm, soil depth 60-100 cm, and $CaCO_3$ content (nodular form) upto 20 per cent support good crop of cotton. The critical limit of AWC has been observed to be 100 mm, below which the yields are uneconomical.*

Rainfed cotton has been observed to give best yield on deep, fine textured soils having good structure. The very fine (with 60 + per cent clay) soils are considered to be critical. On these considerations the criteria for determing the suitability of Swell-Shrink soils for cotton cultivation has been developed and applied to Khapri watershed near Nagpur indicating that the criteria works well in semiarid to subhumid ecosystem of central plateau under rainfed conditions.

Cotton is an important cash crop grown widely in the tropical and sub-tropical areas of the world (Fig. 1). In India, it is grown in about 7 m ha areas of swell-shrink soils (black cotton soils) under rainfed conditions, and alluvium-derived soils under irrigated conditions. Of the total area, 38 per cent occurs in Maharashtra and 19 per cent in Gujarat. It grows well on a wide range of deep soils. It requires soils amenable to good drainage. The most common restriction for its cultivation is waterlogging. Shallow soils overlying an impermeable rock are unsuitable. It tolerates fairly wide range of soil acidity and alkalinity better than most major crop plants.

In general, while growing the cotton, no proper consideration is given to soil and site properties. This has resulted in overall low yield. Robinson *et al.* (1969) reported low yield of seed cotton of the order of 5600 kg ha^{-1} from Typical Gezira Clay and the Mopani soils of the Sabi Valley of Zimbabwe. Therefore, a need is felt to develop a strategy to evaluate and determine soil suitabilities in terms of crop performance for better utilisation of our soil resources for cotton cultivation.

LAND EVALUATION CONCEPT AND NEED

The performance of any crop, is largely dependent on soil parameters (such as depth, texture, drainage, etc.) as conditioned by climate, and topography. The study of soil-site characteristics for predicting the crop performance of an area forms land evaluation. According to van Wambeke and Rossiter (1987) land evaluation is the ranking of soil units on the basis of their capabilities (in prevailing circumstances and management and socio-economic levels) to produce optimum returns per unit area.

Natural resource surveys provide basic data on land resources, which without interpretations, have limited value to land users, planners and decision makers (Beek, 1981). They need guidance as to which crops are suitable for a particular land parcel for profitable land use. Such evaluation entails an assessment of land performance under specific land utilization types.

The USDA land capability classification is a general purpose land evaluation system useful for farm planning with bias on conservation. The parametric approaches are site-specific. They have limited use without calibration. The land suitability classification is a specified land assessment system suitable for qualitative and quantitative evaluations. The FAO (1976) framework provides a set of principles from which land evaluation can be established to suit the local conditions. It involves the interpretation of basic data on climate, soil, vegetation and qualities of land. The range of land use is considered to be limited within the physical, economic and social context of an area. Dumanski and Stewart (1983) illustrated how the adoption of methodology of FAO agroecological zoning in prediction of crop potentials for Canada and provided the bases for assessing land suitability for specific crops.

The present attempt is to construct a base by which deductive reasoning may lead to ranking of land units to evaluate suitability of some Black Cotton Soils of Maharashtra and Gujarat in terms of their qualities for cotton cultivation by using a modified soil-site suitability criteria developed for the purpose.

MATERIAL AND METHODS

For the present study, areas from Maharashtra and Gujarat were selected. The extent of swell-shrink soils (Black Soils) in these states is depicted in figure 2 and climatic conditions in figure 3, respectively. The soil maps showing soil families on 1:250,000 scale were used. These soils have been developed under semi-arid and subhumid climatic conditions, mainly on basalt and basalt derived alluvium. They are fine textured, dark in colour, and have high shrink-swell potential (COLE: 0.09 to 0.10), low infiltration rate (0.1 to 0.5 cm hr^{-1}), poor workability and rather a narrow range of workable moisture limits. Under irrigated conditions, they are prone to waterlogging due to low to very low

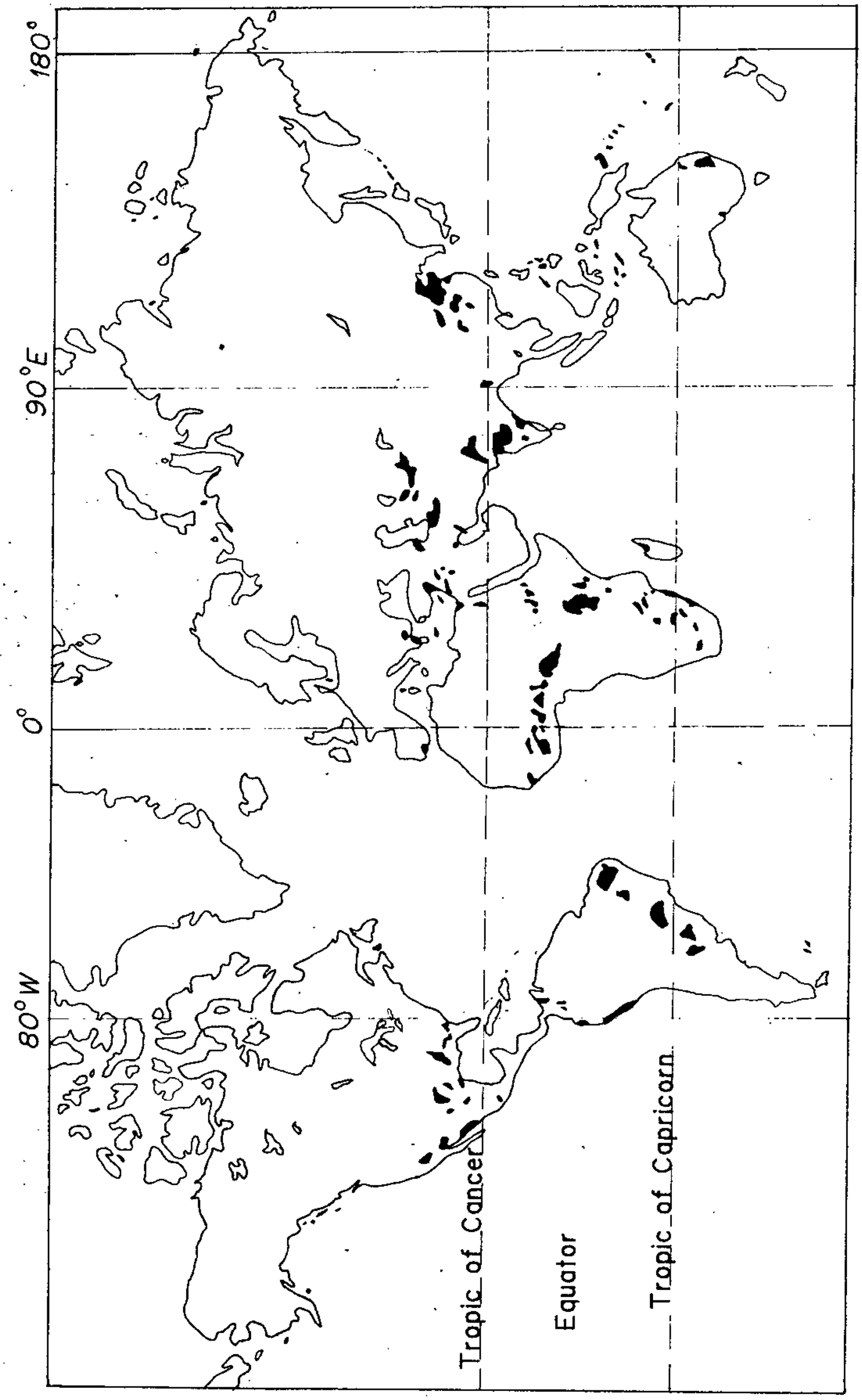

Figure 1. Cotton growing areas in the world (Source : Munro, 1987)

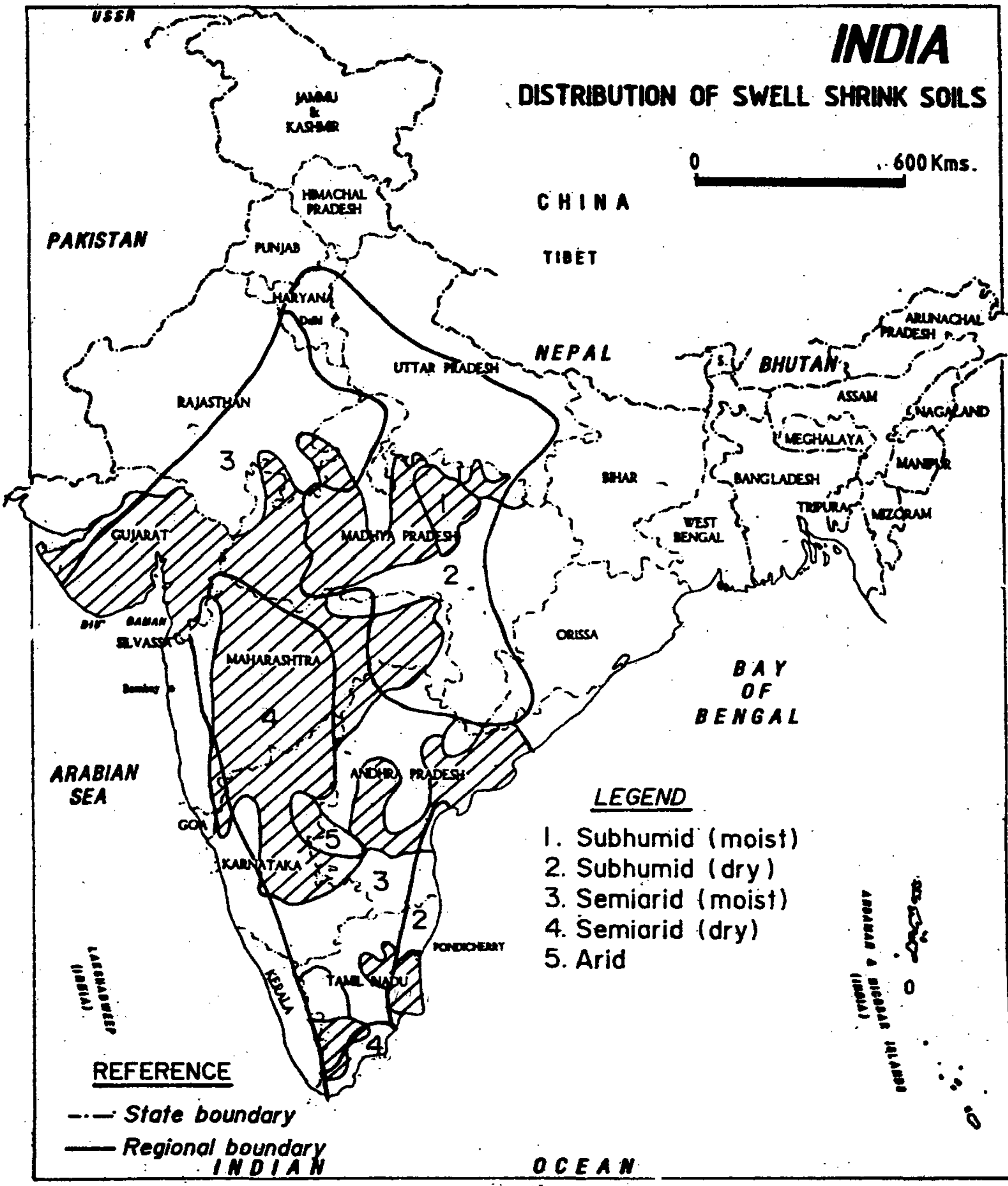

Figure 2. Distribution of swell-shrink soils in India.

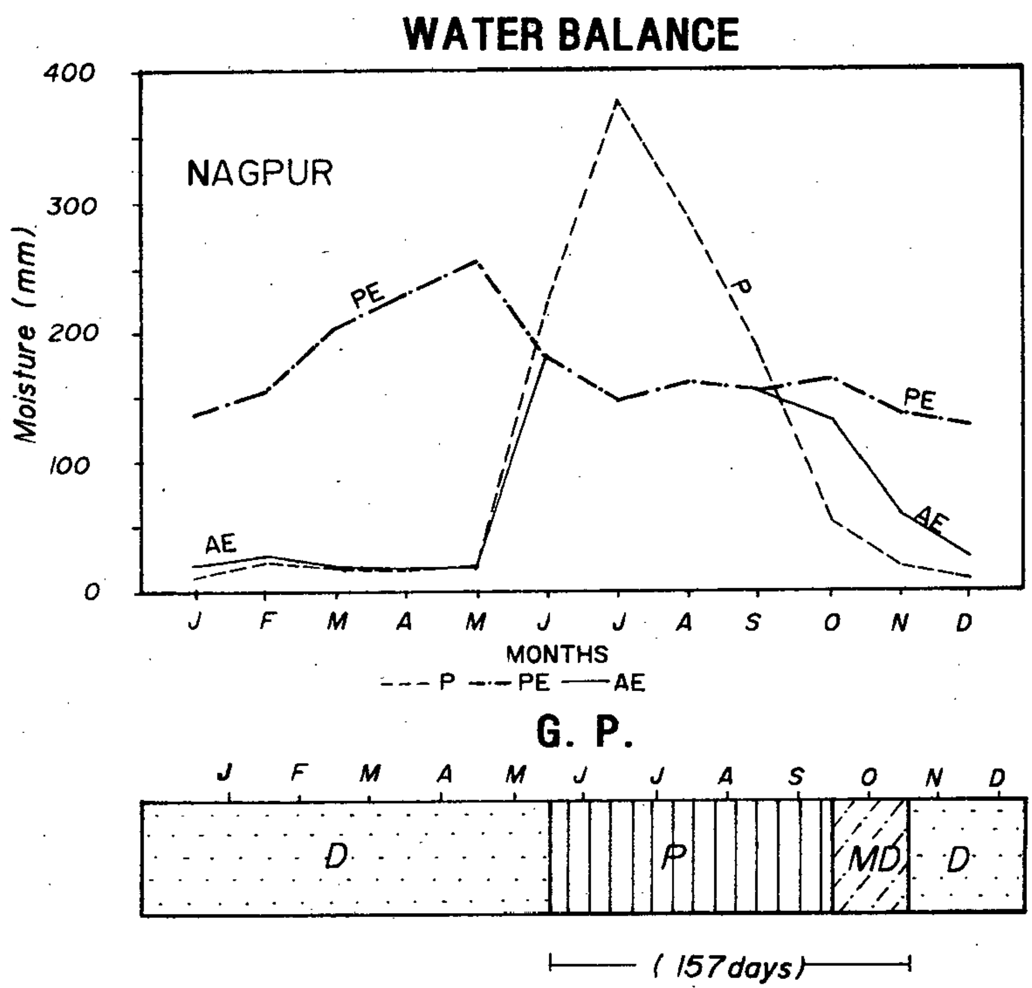

Figure 3. Water balance & growing period (GP) at Nagpur station.

TABLE 1. relationship of cotton performance to soil-site parameres

No. of observations	Intercept	Regression Coefficients					
		Rainfall (mm) X_1	Soil depth (cm) X_2	GP (weeks) X_3	Clay (%) X_4	$CaCO_3$ (%) X_5	R^2
VERTISOLS (Deep Black Soils)							
10	-12.0748	0.0172* (0.0045)	-0.0313 (0.0295)	-0.2043 (0.1465)**	0.1803 (0.2255)	0.7278* (0.2243)	0.8583
			Soil depth (cm) X_1	Silt (%) X_2	$CaCO_3$ (%) X_3	AWC X_4	R^2
ASSOCIATED	INCEPTISOLS & ENTISOLS		(medium & shallow black soils)				
13	-3.2940		0.0323* (0.0133)	-0.1624* (0.0628)	-0.2633* (0.0721)	0.0158* (0.0065)	0.8909

Source: sehgal,*et al.* 1989: *Significant at 5% level; **Standard error of variable.
GP : Growing Period.

permeability. The soil-site characteristics were evaluated based on the criteria of FAO (1976), Sys (1985) and NBSS (1986) and expressed in terms of their degree of limitations (0, 1, 2, 3, 4)., The limitation of 2, is considered critical at which the expected yield declined significantly and the cultivation is considered marginally economic.

Basic soil parameters, such as drainage, depth, texture, carbonates, etc. as well as meteorologic factors like rainfall and temperature were evaluated. Yield data from experimental stations and farmers' fields were compared in relation to soil-site parameters covering Vertisols and associated Inceptisols and Entisols through a linear equation:

$$Y = a + b1x1 + b2x2 + b3x3 + b4x4 + b5x5 + u \quad \text{.............................. (i)}$$

where:

Y = yield of the crop, q ha^{-1}

x1 = rainfall, (mm);

x2 = soil depth, (cm);

x3 = growing period; (weeks);

x5 = calcium carbonate, (per cent);

u = random error;

a = intercept;

b1 = partial regression coefficient.

For computing optimum range of any parameter for crop performance, a quadratic model was developed in the following form:

$$y = a + bx + cx^2 + u \quad \text{................ (ii)}$$

where:

y = yield of the crop (q ha^{-1})

x = explanatory variable (rainfall, calcium carbonate)

u = random error

a = intercept

b,c = regression coefficient

RESULTS AND DISCUSSION

Linear equation model fitted for soil-site parameters and crop performance (Table 1) indicated that these factors explain variability from 75-85 per cent. Rainfall, soil depth and calcium carbonate content showed significant impact on cotton yield in Vertisols. This relationship suggested that the yield increased with increase in value in any of the parameters, but only within narrow limits. This was confirmed by fitting a quadratic equation from which it became evident that some parameters, such as rainfall, soil depth, lime content, etc. have significant influence on cotton yield (Fig. 4). It was observed that cotton yield increased with increase in rainfall upto 1000 mm.

Soil depth is an important criterion for land evaluation. Most crops produce excellent yields with an effective root zone depth of 90-100 cm (Sys, 1985). It is (Fig. 4) evident that cotton is successfully grown in deep soils. The field studies on Black Soils (NBSS Staff, 1986; Bhaskar *et al.* 1987; Sehgal *et al.* 1989) suggest that a depth of 100-120 cm is optimum for cotton cultivation. The soils having 60-100 cm depth support good crop; and others having less than 60 cm depth are not economical to grow cotton (Bhaskar *et al.* 1987). The depth of 50 cm was considered critical below which cultivation of cotton becomes marginally economical or uneconomical.

Free lime has an antagonistic effect on the availability of some plant nutrients. High lime content in soils, in general, is considered one of the major determinants of crop yield (Landon, 1984). The correlation of $CaCO_3$ to yield of over 20 cotton growing stations in India (Fig. 4) show optimum yield at calcium carbonate content upto 15 per cent in Vertisols and 20 per cent in associated soils. Such high content of free lime in soils should normally induce chlorosis and/or cause nutritional imbalance. In the swell-shrink soils, the moisture may be limiting to show the effect of free lime on chemical properties. Besides, the morphology of these soils suggests that lime nodules, being inert, might be acting as soil conditioners in improving the physical condition of the soils.

The yield response to moisture storage in the solum indicate that maximum yield of cotton could be obtained at 220 mm of available water capacity. Cotton being a long duration crop, even with its deep-rooting system, it experiences significant decline in yield in soils having low (100 mm) moisture storage. It also suffers from high rainfall-induced-anaerobic conditions on soils with low permeability and poor runoff. The moisture stress due to intermitent dry spells during and after rainy season, especially in shallow soils adversely affects plant growth and ultimately the yield. The critical limit of moisture storage capacity has been observed to be 100 mm, below which the yields are uneconomical.

Texture is considered important and its influences can be modified by

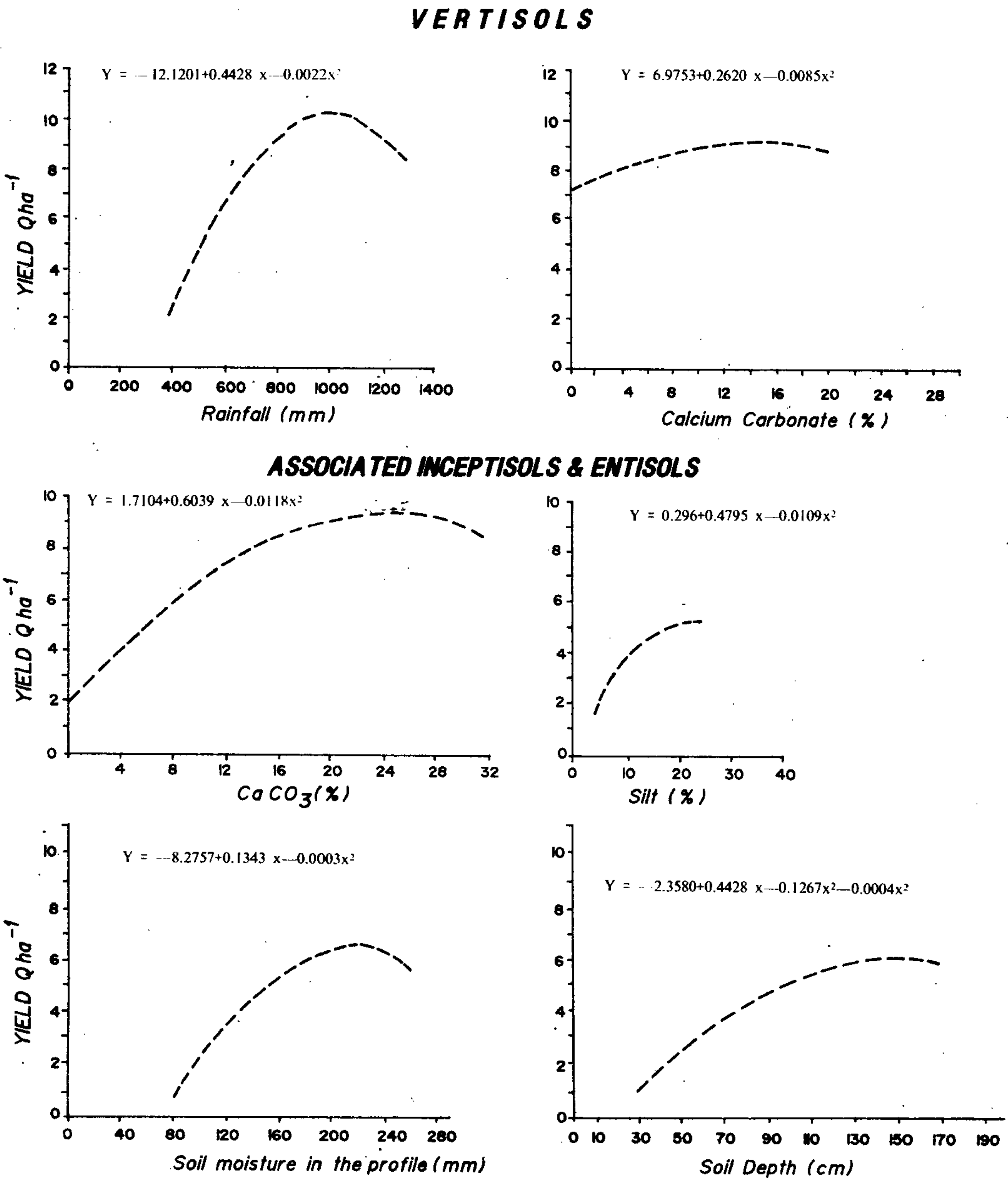

Figure 4. Influence of different parameters on yield of cotton

Source: sehgal, *et al.*(1989)

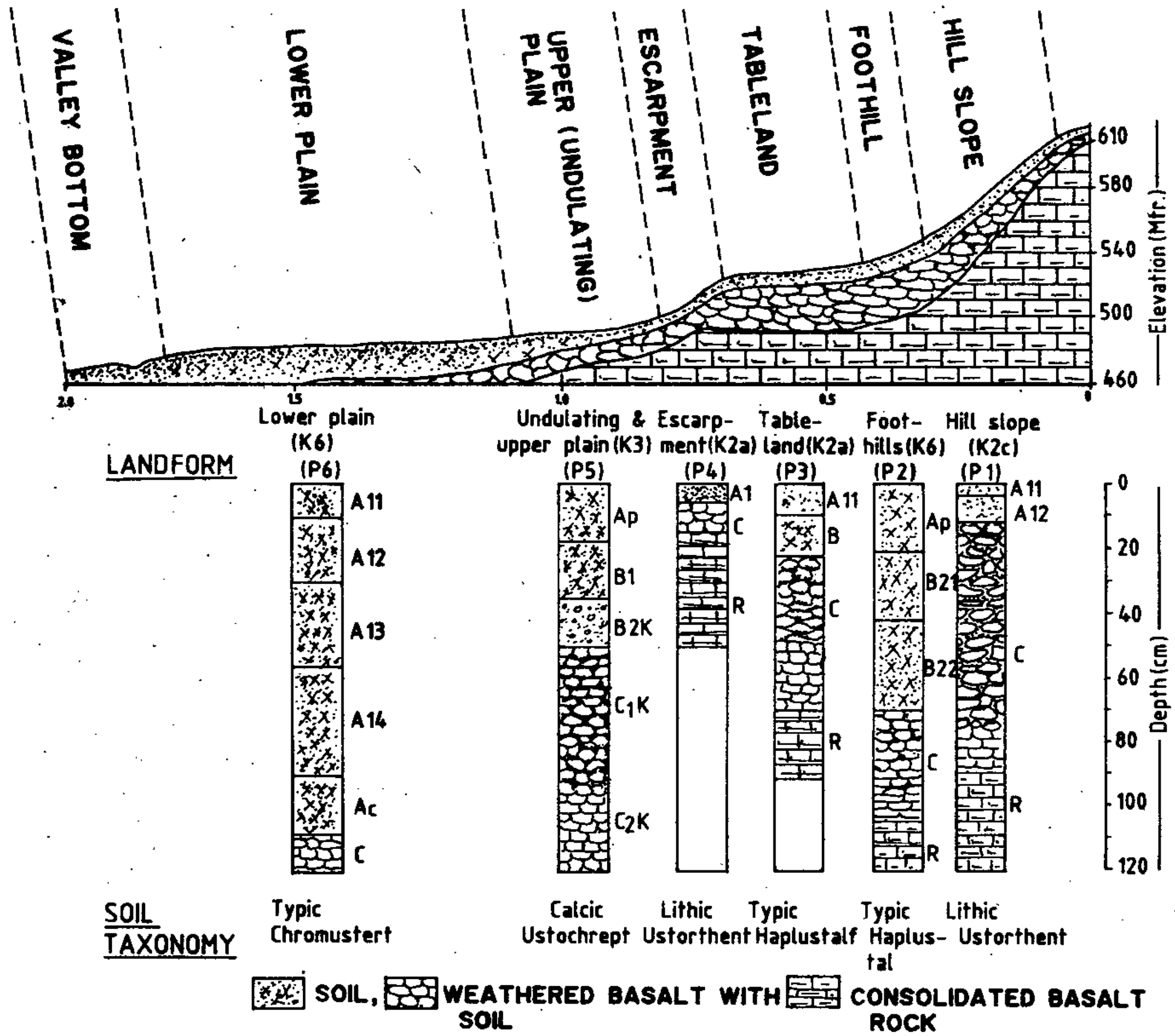

Figure 5. A cross-section of the Khapri watershed area showing different land forms and soils

TABLE 2. Optimum value of different parameters for maximum yield of cotton

Vertisols		Associated Soils			
Rainfall (mm) X_1	$CaCO_3$ (%) X_2	Depth (cm) X_1	Silt (%) X_2	$CaCO_3$ (%) X_3	AWC X_4
1000	16	160	20	26	220

Source: Sehgal, *et al.* 1989

structure, clay minerals, organic matter, lime content, etc. Although, cotton is known to grow well in medium and fine-textured soils with well developed structure; it has also been reported to grow satisfactorily in sandy soils around Victoria lake in Tanzania (Munro, 1987). The Black Cotton Soils are not necessarily the most suitable soils as they are rich in montmorillonite, are difficult to manage, being too sticky when wet and too hard when dry to produce a good tilth (Munro, 1987). Texture is therefore evaluated in conjunction with structure in terms of permeability and workability of soil. Under rainfed conditions, cotton has been observed to give best yield on deep, fine textured soils having good structure. The very fine (with 60 + % clay) as well as coarse loamy and sandy soils are considered to be critical in the evaluation criteria.

Based on the above considerations and field data available, modified criteria has been developed for determining suitability of swell-shrink (Vertisols and associated Inceptisols and Entisols) soils for cotton growing (Table 2). In the cirteria, climatic parameters and other incorrectable parameters, such as soil depth, texture (with or without structure) have been treated differently for final evaluation in view of their permanent nature.

Evaluation of Mapped Soils

The mapped soils from Maharashtra and Gujarat (Table 4) are matched with the soil-site suitability criteria for cotton (Table 3). The kind and degree of limitation and suitability class were determined and evaluated (Table 5). It showed that all the soils are not equally suitable for cotton. Some are moderately suitable, while the others are marginally suitable or even unsuitable for cotton. The present suitability class can, however, be improved if the severity of correctable limitation such as salinity/or base saturation, is altered through soil amelioration measures. The severity of limitation(s) in case of soil depth, can not be corrected and as such the potential and present suitability of a soil unit remains the same.

TABLE 3. Climatic and soil-site suitability requirements of cotton at different degrees of limitations*

Soil-Site characteristics	Degree of limitation				
	0	1	2	3	4
	S1		S2	S3	N1
CLIMATIC CHARACTERISTICS					
Total rianfall (mm)	1200-1000	1000-850	850-700	.700-550	550
Rainfall during growing season (mm)	1000-850	850-750	850-700	700-550	550
Length of growing season (days)	210-180	180-150	150-120	120-100	100
Mean temp. during growing season (°C)	28-26	26-24	24-22	22-20	20
Mean max. temp. during growing season(°C)	35-32	32-28	28-26	26-24	24 40
Mean R.H. in growing season	50	50-60	60-70	70-80	80
Length of Dry Spells (weeks)					
July (beginning)	1	1	1-2	2-3	3-4
August (end)	1	1-2	2-3	3+	4+
SITE CHARACTERISTICS					
Slope (%)	0-1	1-3	1-3	3-5	5-8 or more
Brosion	e0	e1	e2	e2-3	e3
Drainage (Internal & External)	Well	Well	Mod.well	Imperfect somewhat excess	poor excess
Ground wate table (m)	3	2-3	1-2	1	1
AWC (mm/m)	200	150-200	100-150	50-100	50
Stoniness (surface)	3	3-15	15-40	40-75	75
SOIL CHARACTERISTICS					
Texture	c,sc (fine) (structural)	cl,sicl, sc (F.loamy, (F. silty)	l,sil, csl (very fine)	sl, ls (coarse loamy)	s (sandy)
Coarse fragments (Vol. %)					
within 50 cm	5	5-15	15-40	40-75	75
below 50cm	5-15	15-40	40-75	75	--
Effective depth (cm)	120	120-80	80-50	50-25	25
$CaCO_3$ (%)	10	10-20	20-30	30-40	40
ECe (dsm^{-1})	2	2-4	4-8	8-15	15
Loamy texture	10	10-15	15-25	25-40	40
ESP					
Fine texture	5	5-10	10-15	15-25	25

* Modified version of earlier model based on multivariate regression yield model (after Sehgal, *et al.* 1989).

TABLE 4. Soil-site characteristics of the mapped units

Symbol Map Units	Rain-fall (mm)	Slope	Drainege	Tex-ture	Depth (cm)	Ero-sion	Stoniness (% area covered)	Sali-nity	Sodi-city	Major constraints	Classi-fication
BEED, MAHARASHTRA											
1. I2E3/Ce1g1	603	C	Well	Clay	25-50	e1	15-40	Nil	Nil	Depth, erosion stoniness	Ustochrept Ustorthent
2. I2E3/Ce1G	603	C	Well	Clay	25-50	e1	40-75	Nil	Nil	Depth, erosion stoniness	-id-
3. E2I3/Le2c	603	C	Well	Loam	10	e2	Nil	Nil	Nil	Depth, erosion, stoniness	Ustorthent Ustochrept
4. I4E3/Ce1c	603	C	Well	Clay	25-50	e1	Nil	Nil	Nil	Depth, erosion, stoniness	Ustochrept Ustorthent
5. VII3/Ce1b	603	B	Mod.well	Clay	100-150	e1	Nil	Nil	Nil	Drainage, erosion,	Chromustert Ustochrept
6. I6E7/Ce1c	603	C	Well	Clay	25-50	e1	Nil	Nil	Nil	Depth, erosion,	Ustochrept Ustorthent
7. E6R/Ce2G	603	C	Somewhat Excess.	Clay	10	e2	40-75	Nil	Nil	Depth, erosion, stoniness	Ustorthent, Rocky
8. I2I3/Ceg1	603	C	Well	Clay	25-50	e1	15-40	Nil	Nil	Depth, erosion, coarse fragments stoniness	Ustochrept
9. VII13/Ce1b	603	B	Mod. well	Clay	100-125	e1	Nil	Nil	Nil	Drainage, erosion,	Chromustert Ustochrept
10. VIE7/Ce1b	603	B	Mod. well	Clay	100-125	e1	Nil	Nil	Nil	Drainage, erosion,	Chromustert Ustorthent
11. E3R/Ce2G	603	C	Well	Clay	10-25	e2	40-75	Nil	Nil	Depth, erosion, rocky, stony	Ustorthent Rocky
RAJKOT, GUJARAT											
1. I2E36/Cbe1	555	A (B)	Mod. well	Clay	50-75	e1	Nil	Nil	Nil	Drainage, depth, erosion	Vertic Ustochrept-Lithic Ustorthent
2. Re32/Lee3	555	D (E)	Well	--	25-50	e3	40-75	Nil	Nil	Slope, depth, erosion	Rock outcrops-Lithic Ustorthent
3. E28I26/Ece3	555	B (C)	Somewhat Excess	Clay	10-25	e3	40-75	Nil	Nil	Slope, depth, erosion	Lithic Ustorthent Lithic Ustochrept
4. VI129/Cbe1	555	A (B)	Mod. well	Clay	75-100	e1	Nil	Nil	Nil	Erosion, slope	Lithic Chromustert Vertic Ustochrept
5. I25I30/Cce2	555	A (B)	Well	Clay	25-50	e2	Nil	Nil	Nil	Depth, erosion,	Lithic Ustochrept Vertic Ustochrept
6. I29VI/Cbe1	555	A (B)	Mod. well	Clay	50-75	e1	Nil	Nil	Nil	Drainage, depth	Vertic Ustochrept-Typic Chromustert
7. Si3/Cs6e2	A	Poor	Well	Clay	100-150	e2	Nil	Very Severe	Nil	Drainage, salinity	Typic Halaquept
8. VI130/Es5n3	555	A (B)	Poor	Clay	75-100	e1	Nil	Severe	Severe	Drainage, salinity sodicity	Typic Chromustert Vertic Ustochrept
9. SP	Salt	Pan									

TABLE 5. Degrees of mapped soil limitations and overall suitability class for cotton

Map Units Units	Cli-mate	Slope	Drain-age	Tex-ture	Depth	Ero-sion	Stoni-ness	Sali-nity	Sodi-city	Suitability class Present	Potential
BEED, MAHARASHTRA											
1. I2E3/Celgl	3	3	0	0	3	1	1	0	0	S3	S3
2. I2E3/CelG	3	3	0	2	4	2	0	0	0	S3	S3
3. E2I3/Le2c	3	3	0	2	4	2	0	0	0	N2	N2
4. I4E3/Celc	3	3	0	0	3	1	0	0	0	S3	S3
5. VI13/Celb	3	2	2	0	0	1	0	0	0	S3	S3/S2
6. I6E7/Celg	3	3	0	0	3	1	0	0	0	S3	S3
7. E6R/Ce2g	3	3	3	0	4	2	2	0	0	N2	N2
8. I2I3/Celgl	3	3	0	0	3	1	1	0	0	S3	S3
9. VI13/Celb	3	2	2	0	0	1	0	0	0	S3	Se/S2
10. VIE7/Celb	3	0	2	0	0	1	0	0	0	S3	S3/S1
11. E3R/Ce2G	3	3	0	0	4	2	2	0	0	N2	N2
RAJKOT, GUJARAT											
1. I29E26/Cbel	3	2	1	0	2	1	0	0	0	S3	S3/S2
2. RE32/Lee3	3	4	0	0	3	3	2	0	0	S3	S3
3. E28I26/Ece3	3	3	3	0	4	3	2	0	0	N2	N2
4. VI129/Cbel	3	2	2	0	1	1	0	0	0	S3	S3/S2
5. I25I30/Cce2	3	2	0	0	3	2	0	0	0	S3	S3
6. I29VI/Cbel	3	2	2	0	2	1	0	0	0	S3	S3/S2
7. SI3/Cws6	3	2	4	0	1	1	0	4	4	N2	N2
9. Salt Pan										N2	N2

Suitability Structure

ORDER (kind of suit.)	CLASS (degree of suit)	SUBCLASS (kind of limit)	UNIT (management needs)
	(S1 - Suitable	S2m	(S2e1
S	(S2 - Mod. suit.	------S2e ------	(S2e2
	(S3 - Marg. suit.	S2me, etc.	(S2e3,etc.
	(N1 - Not suit. (currently)		
N	(N2 - Not suit.(permanently		

Suitability: criteria — S1 - Limitation of 1 (upto 3); S2 - Limitation of 1 and/ or of 2 (upto 3 correctable or upto 1 incorrectable); S-3 - Limitation of 2 and/or of 3 (upto 3 correctable or upto 1 incorrectable) N1 - Limitation of 3 and/or of 4 (upto 3 correctable or 1 incorrectable).

TABLE 6. Suitability of mapped soils in relation to actual and potential yield in Khapri watershed near Nagpur

Suitability Class & Yield	Mapped Units							
	K2(a)	K2(b)	K2(c)	K3(a)	K4	K5	K6	K7
Suitability class for cotton	N1	N2	N2	S3	S2	S1	N1	S2
Actual yield (q ha^{-1}) (Farmers level of management)	--	--	--	5.0 (33)	8.0 (53)	12.5 (82)	3.7 (24)	8.7 (57)
Potential yield (q ha^{-1}) (Optimm level of management)	5.2 (34)	--	--	11.4 (75)	12.3 (81)	15.2* (100)	4.3 (28)	14.3 (94)

Figures in parentheses show percentage of maximum yield under optimum management practices.
Maximum potential yield as observed in the area taken at 100.
Source: Balbudhe 1990, M.Sc. (Agri.) Thesis, PKV, Akola.

APPLICATION

The soil-site suitability criteria were applied to a Khapri watershed (Fig. 5) near Nagpur, and suitability of different soil units evaluated (Table 6). It shows that the actual yields obtained correlate well with the predicted yields under the established suitability classes as determined by using the suitability criteria, suggesting that the criteria works in the semiarid to subhumid eco-regions of central plateau under rainfed conditions.

It may be concluded that climatic and soil-site parameters play significant role to maximise cotton yield. The statistical approach, assists in finding limits of different parameters to predict yield potential. Using this as the base and using actual field experimental data from different agro-ecological regions, a refined soil-site suitability criteria for cotton have been evolved, and suitability of different mapped soils were determined. The criteria, when applied to soils of a watershed near Nagpur, correlate well with the actual yield data suggesting that the criteria works and may find application under other comparable situations.

REFERENCES

Balbudhe, P.H. (1990) Soil moisture availability under different landforms in Khapri (Barokar) watershed near Nagpur - utilisation for land use planning. *M.Sc. (Agri) Thesis. PKV*, Akola (M.S.).

Beek, K.J. (1981) From soil survey interpretation to land evaluation. Part-I. From the past to the present. *Soil Survey & land Evln.* **1**, 6-12.

Bhaskar, K. S., Lal, S., Challa, O.& Madavi, S.H. (1987). Effect of soil depth on cotton yield. *J. Maharashtra Agric. Univ. 12*(1), 139-140.

Dumanski, J.& Stewart, R.B. (1983) Crop production potentials for land evaluation in Canada (Quoted from Davidson D.A. 1984). *Soil Survey & Land Evln. 4,* 71-76.

F.A.O. (1976). *Soil Bull. 32,* FAO, Rome.

Landon, J.R. (ed.) (1984) Booker Tropical Soil Manual, *Booker Agriculture International Ltd. Publ.* pp. 269-307.

Munro, J.M. (1987) Cotton (2nd Ed.), *Longman Sci. & Tech.* England, 436 p.

NBSSLUP (1986) The soils of Mondha village (Nagpur) for Agro-technology transfer. *Soil Bull.* 11, NBSS & LUP publ., 65 p.

Robinson, G.H., Magar, W.Y. & Rao, K.D. (1969) Soil properties in relation to cotton growth. in: Siddiq & Hughes - Eds. (1969) Cotton growth in the Gezira environment. *Agric. Res. Crop: Wad Medani,* Sudan, 5-16 p.

Sehgal, J.L., Challa, O., Gajja, B.L., Yadav, S.C. (1989) Suitability of swell Shrink soils of India for crop growth. in: Van Cleemut et. al, ed.. (1989). Soil for Development. *ITC Ghent Publ. Series 1,* 29-53 p.

Sys, C.,(1985.) Land Evaluation Part I-III. *Agricals Publs. 7,* Ghent (Belgium).

Van Wambeke, A. and Rossiter, D.(1987) Automated land evaluation systems as a focus for soil research. *IBSRAM News Letter 6,* October 1987.