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Comparison of Different Land Evaluation Techniques for Evaluating the Soil Suitability for Rainfed Hybrid Cotton

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Abstract: This study compares the performance of three land evaluation methods, *viz.*, FAO Simple Limitation, Storie Index and InfoCrop simulation model, for assessing the suitability of cotton soils (represented by nine different soil series) of Nagpur district, Maharashtra, India. The Simple Limitation method categorised Wardha, Parseoni and Bhugaon soil series as moderately suitable and the remaining are marginally suitable for rainfed cotton. The values of Land Index, determined by the Storie Index method, ranged from 20.3 for Manori series to 55.3 for Bhugaon series. Rainfed cotton yields, simulated by InfoCrop model ranged from 761 kg ha^{-1} in Manori series to 2881 kg ha^{-1} in Katol series. The Relative Yield Index (RYI) ranged from 0.154 for Manori series to 0.585 for Katol series. Kinhala, Katol and Takali soil series, classified as marginally suitable by the Simple Limitation method, were upgraded as moderately suitable by Sys parametric method. The results of InfoCrop model justified this up-gradation with the high values of RYI that ranged from 0.574 to 0.585. Soils of Manori and Hatodi series are not suitable for cultivating rainfed cotton. Soil depth, hydraulic conductivity and plant available water in the soil were critical factors governing cotton yield and ranking of soils for their suitability.

Key words: *InfoCrop-cotton model, land evaluation, Sys parametric technique, Relative Yield Index, rainfed hybrid cotton*

Introduction

Around 38% of the global cotton area of 33.6 mha is in India. The area under cotton in India increased from 7.63 mha in 2003-04 to 12.43 mha in 2017-18. Despite widespread adoption of hybrid cotton (Bollgard II), increased nutrient and water use, the productivity of cotton is low, around 500-560 kg ha^{-1}. One of the reasons attributed for this is the extension of cotton cultivation to red soils, shallow soils, paddy soils that are not ideally suited for cotton (Naidu *et al.* 2006; Venugopalan *et al.* 2017). Although economics, primarily, decides the choice of crop, cultivation of cotton in less suitable soils would reduce yields besides further deteriorating the productive capacity of these soils. Therefore, there is a need to evaluate and prioritise the soils for cotton cultivation as per the soil suitability and also, to devise specific technologies to support cotton cultivation in less productive soils.

Land evaluation techniques evaluate the potential and limitations of a parcel of land for its intended use; in this case, rainfed cotton cultivation. The FAO framework for land evaluation (FAO 1976) contains a standard set of principles and concepts for land evaluation. The land evaluation techniques could be qualitative, semi-quantitative or quantitative. Qualitative techniques express suitability based on the limitation of land characteristics; semi-quantitative

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parametric approach provides a numerical rating of these limitations (Sys *et al.* 1991). Simulation models give an idea of crop yield and its temporal variability (Van Lanen *et al.* 1992). Crop simulation models like WOFOST, DSSAT, APSIM are widely used for quantitative land evaluation to provide quantified estimates of crop yield and the effect of moisture limitations (De La Rosa and Van Diepen 2002; Rossiter 2003; Wu *et al.* 2006; Manna *et al.* 2009). InfoCrop, an indigenous crop model (Aggarwal *et al.* 2006), has been calibrated for cotton (Hebbar *et al.* 2008), validated (Venugopalan 2007) and applied for predicting cotton production for climate change studies (Hebbar *et al.* 2013) and for developing land quality indices for rainfed cotton (Venugopalan *et al.* 2014). Many researchers have compared different land evaluation methods (Hopkins 1977; Anderson 1987; Steiner 1987; Rabia 2014), but there are very few studies comparing simulation model-based approach with conventional techniques of land evaluation (Manna *et al.* 2009), particularly for cotton.

Cotton is a major crop of Nagpur district of Maharashtra, located in Central India. Cotton is cultivated on a wide range of soils (Table 1). The area of the district under cotton increased from 73400 ha in 2003-04 to 145168 ha in 2017-18. The objective of this study is to compare the performance of a qualitative, a semi-quantitative parametric and a quantitative land evaluation technique for assessing the suitability of land under nine different soil series for the cultivation of rainfed hybrid cotton (Bollgard II) and delineate areas of less productive soil

Methods and Materials

The study area, Nagpur district (20^0 35" to 21^0 44" N; $78^0$15" to $79^0$40" E), is characterised by the sub-humid tropical climate. The mean annual temperature is 26.9^0C, and the average annual rainfall is 1012 mm. The South-west monsoon (June-September) accounts for about 85% of the annual rainfall. We selected nine soil series (Challa *et al.* 1999) representing the cotton-growing soils of the district (Fig. 1) for soil suitability analysis for cotton using both qualitative and quantitative methods, *viz.*, Simple Limitation Method (Sys *et al.* 1991), Storie Index Method (Storie 1978) and InCrop Simulation Model (Aggarwal *et al.* 2006). The salient Physico-chemical properties of the selected soil series are presented in table 1.

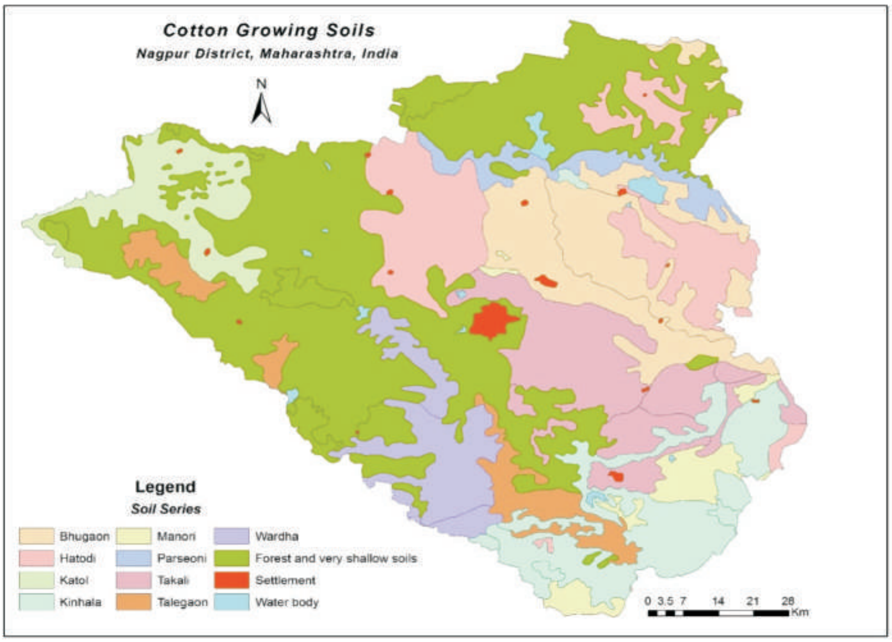

Fig. 1. Cotton growing soils of Nagpur district

Table 1. Important physical and chemical properties of the soils of the study area

Series (classification)	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	pH	OC (%)	$CaCO_3$ (%)	CEC Cmol kg^{-1}	BS (%)	ESP
Kinhala (Fine, montmorillonitic, hyperthermic, Lithic Haplusterts)	145	14.8	31.5	53.7	8.5	0.4	Nil	51.2	93.1	0.6
Katol (Fine, montmorillonitic (calcareous), hyperthermic, Lithic Haplusterts)	125	10.08	32.29	57.61	8.45	0.39	5.82	50.52	91.58	1.38
Talegaon (Clayey, montmorillonitic, hyperthermic, Typic Haplusterts)	28	17.53	30.14	52.33	7.84	0.44	Nil	50.54	96.69	0.61
Hatodi (Coarse-loamy, mixed, hyperthermic, Typic Haplustepts)	35	46.25	17.98	35.77	7.48	0.64	Nil	25.59	78.55	0.78
Wardha Fine, montmorillonitic (calcareous), hyperthermic, Typic Haplusterts	150	14.32	32.03	56.45	8.16	0.44	11.27	49.40	96.99	0.49
Parseoni Coarse-loamy, mixed, hyperthermic, Typic Haplustepts	75	74.27	7.84	17.89	6.73	0.98	Nil	15.35	89.93	0.58
Bhugaon Fine, montmorillonitic (calcareous), hyperthermic, Typic Haplusterts	125	12.94	29.92	57.14	8.10	0.41	Nil	50.38	89.33	0.49
Takali Fine, montmorillonitic, hyperthermic, Typic Haplusterts	125	17.22	29.66	53.13	8.16	0.43	Nil	50.94	93.52	0.58
Manori Fine-loamy, mixed, hyperthermic, Typic Ustorthents	28	35.00	25.06	39.94	8.26	0.69	2.12	33.30	92.29	0.77

Suitability analysis by Simple Limitation Method

In this method, the relevant land characteristics were evaluated on a relative scale of limitations (Sys *et al.* 1991). Limitations were imposed when land characteristics deviate from the optima. There are five levels of limitations, *viz.*, no limitation (0), slight limitation (1), moderate limitation (2), severe limitation (3) and very severe limitation (4). The evaluation is done by matching the land characteristics with the requirement of the crop (Naidu *et al.* 2006)' and by identifying the limitation level for each land characteristic. The final soil suitability class based on the number and intensity of the limitation(s). The soil suitability class are defined as Highly suitable (S1) - no or only four slight limitations; Moderately suitable (S2) - more than four slight limitations and/or not more than three moderate limitations; Marginally suitable (S3) - more than three moderate limitations and/or more severe limitation (s), Currently not suitable (N1) - very severe limitation that can be corrected and permanently not suitable (N2) - very severe limitations that cannot be corrected.

Suitability analysis by Storie Index Method

The Storie Index is a semi-quantitative parametric technique to assess the productivity of soil from the four characteristics - soil profile (A), the texture of surface soil (B), land slope (C) and factor (X), characteristics other than those identified in factors (A), (B) and (C) like drainage, alkalinity, fertility, acidity, erosion and micro-relief. In the present study, we considered both climate and soil characteristics for the suitability analysis of cotton growing soils and minimum dataset (MDS) was used to determine the land index. Depending upon the conditions of the selected factors, a score ranging from 0 to 100% is assigned to each factor, and the scores are then multiplied together to generate a final land index using equation (1) (Storie 1978). If the characteristic of the land is optimal for rainfed cotton, the value of 100 is attributed to that characteristic. A lower value is attributed when the characteristic is less favourable.

$$\text{Land Index} = A \times \frac{B}{100} \times \frac{C}{100} \times \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Where, A = Climatic Characteristics, B = Soil Physical Characteristics, C= Fertility Characteristics

Suitability classes are defined according to the value of the land index, S1: 100-75 (Highly suitable); S2: 75-50 (Moderately suitable); S3: 50-25 (Marginally suitable); N1: 25-12; (Currently not suitable) and N2: 12-0 (Permanently not suitable).

Suitability analysis by a Crop Simulation Model

Info Crop-cotton is a constituent of InfoCrop, a generic model (Aggarwal *et al.* 2006) for quantitative land evaluation. For the simulation of the potential and water-limited yields, daily weather files (1990 to 2012) and soil input files of the nine soil series were prepared in InfoCrop specific format. Genetic coefficients generated earlier for Bt hybrid (Hebbar *et al.* 2008) was used. Used the same weather data for all the soil series. The recommended crop management data- seed rate (2 kg ha^{-1}), sowing depth (4 cm) and the most appropriate sowing date*, i.e*., 20 June, was used for simulation. In all 414 simulations were run for nine soil series to the derived values for potential and water-limited yields under sufficient nutrient supply and no pest incidence conditions. The Relative Yield Index (RYI), calculated as the ratio of the mean (over the years) water limited to mean potential yields, was used to decide the suitability.

The results of the land evaluation were analysed, and the suitability maps of rainfed hybrid cotton were prepared for the selected nine soil series of Nagpur, district using ArcGIS 10.4

Results and Discussion

Among the nine soil series, five namely Kinhala, Katol, Wardha, Bhugaon and Takali were of Vertisols; three namely Hatodi, Talegaon and Parseoni were Inseptisols and one series, Manori was an Entisol. All the Vertisols were very deep (> 100 cm), one Inceptisols, Parseoni was medium-deep (75 cm) whereas the other Inceptisol, Hatodi and the Entisol, Manori were very shallow. Seven of them had clay as the dominant soil size fraction.

The minimum dataset of land characteristics, *viz*., rainfall, soil depth, texture, pH and CEC (Table 2) were used for the qualitative land evaluation of the soil series using Simple Limitation Method. The results of overall ratings indicate that only three series - Wardha, Parseoni and Bhugaon were moderately suitable and the remaining soil series were marginally suitable for rainfed hybrid cotton (BG II). Based on the results of land evaluation, the soil-site suitability map of Nagpur district for rainfed hybrid cotton is depicted in figure 2. Soil depth and pH were the main limiting land characteristics.

Table 2. Rating and suitability class of different soil series for different land characteristics for the basis of qualitative, simple limitation method

Soil series	rainfall		Soil depth		Soil texture		pH		CEC		Overall suitability class
	Rating	Class	Rating	Class	Rating	Class	Rating	Class	Rating	Class	
Kinhala	97	S1	100	S1	100	S1	50	S3	100	S1	**S3**
Katol	97	S1	100	S1	100	S1	55	S3	100	S1	**S3**
Talegaon	97	S1	55	S3	100	S1	80	S2	100	S1	**S3**
Hatodi	97	S1	50	S3	85	S2	90	S1	100	S1	**S3**
Wardha	97	S1	100	S1	100	S1	60	S2	100	S1	**S2**
Parseoni	97	S1	85	S2	70	S2	95	S1	80	S2	**S2**
Bhugaon	97	S1	100	S1	100	S1	60	S2	100	S1	**S2**
Takali	97	S1	100	S1	100	S1	58	S3	100	S1	**S3**
Manori	97	S1	55	S3	95	S1	55	S3	100	S1	**S3**

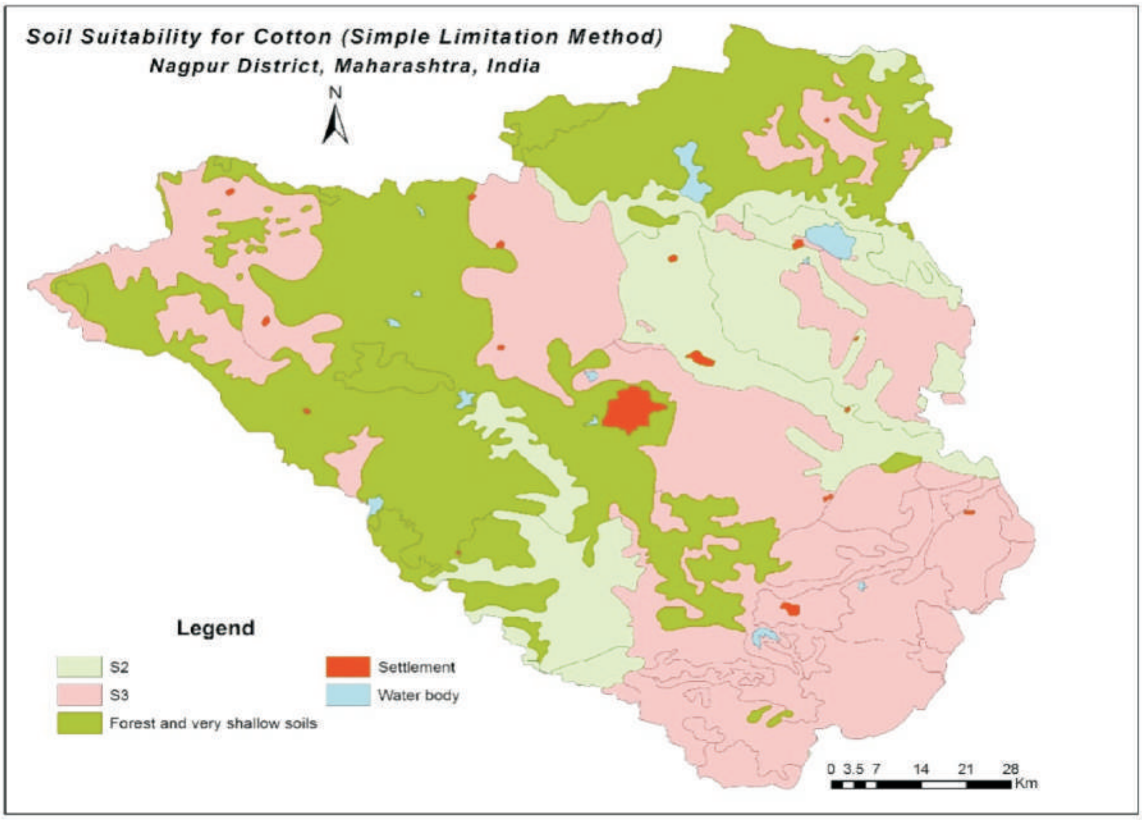

Fig. 2. Soil suitability map for rainfed hybrid cotton using FAO simple limitation technique

Table 3 represents the different land characteristics of the soil series, used in the Storie Index Method along with the corresponding suitability class and Land Index. The results indicate that four soil series, *viz.,* Katol, Wardha, Bhugaon and Takali, with Land Index values in the range of 75-50, were moderately suitable (S2). Four soil series, *viz.*, Kinhala, Talegaon, Hatodi and

Parseoni with Land Index values in the range of 50-25 were classified as marginally suitable (S3). The Manori soil series with a Land Index value of 20.3 was currently not suitable for rainfed cotton. Similar to the simple limitation technique, the major limitations were soil depth and pH. Based on the Storie Index rating, the suitability map for rainfed cotton in Nagpur district is depicted in figure 3.

Table 3. Rating and suitability class of different soil series for different land characteristics for the basis of semi-quantitative, Storie Index method

Series	Kinhala	Katol	Talegaon	Hatodi	Wardha	Parseoni	Bhugaon	Takali	Manori
Land characteristic	↓	---------------------------Rating---------------------------							
	Climatic characteristics								
Rainfall growing season (mm)	97	97	97	97	97	97	97	97	97
	Soil Physical characteristics								
Texture (clay %)	95	95	95	85	95	60	95	95	95
Depth (cm)	100	100	40	40	100	85	100	100	40
	Soil fertility characteristics								
pH	50	55	80	90	60	95	60	58	55
CEC	100	100	100	100	100	80	100	100	100
Land index	46.1	50.7	29.5	29.7	55.3	37.6	55.3	53.4	20.3
Suitability Class	**S3**	**S2**	**S3**	**S3**	**S2**	**S3**	**S2**	**S2**	**N1**

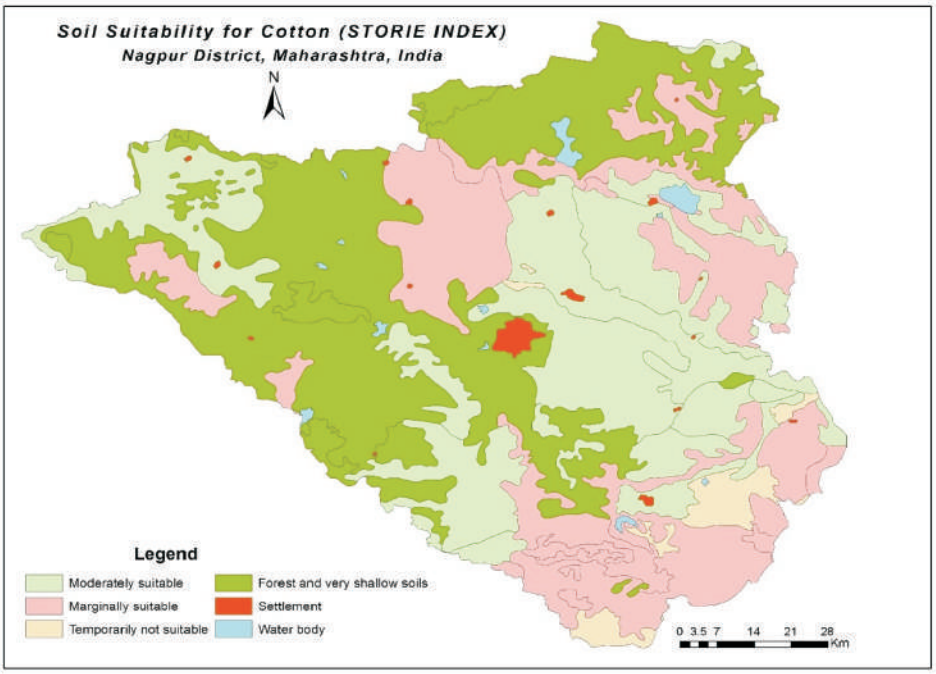

Fig. 3. Soil suitability map for rainfed hybrid cotton using Stories Index method

A summary of the simulations using InfoCrop is presented in table 4. The mean value of potential yield (over 23 years of the simulation) for a hybrid cotton (BG II) was 4927 kg ha^{-1} with a coefficient of variation of 1.4% over years of simulation. Wide variation was observed in the average rainfed (water-limited) seed cotton yields, ranging from 761 kg ha^{-1} in Manori series to 2881 kg ha^{-1} in Katol series (Table 4). The corresponding values for days from sowing to maturity was 136 days in Manori and 152 in Katol series, as against 164 days under potential conditions. The Coefficient of Variation (CV) for seed cotton yield across years of simulation ranged from 46% in Kinhala to 71.6% in Manori series. The Relative Yield Index (RYI), a ratio of potential yield to water-limited yield, was used for quantitative land evaluation. It ranged from 0.154 in Manori series to 0.585 in Katol series. Based on the results of InfoCrop model, the soil suitability map of Nagpur district for cotton production is depicted in figure 4.

Table 4. Simulated days to maturity and seed cotton yield of a typical BG II hybrid using INFOCROP model

Series	Days to maturity				Seed cotton yield (kg ha^{-1})Yield				Ratio of water-limited to potential yield
	Max	Min	Mean	CV	Max	Min	Mean	CV	
Potential	178	156	164	4.3	4992	4655	4927	1.4	
Katol	178	127	152	9.2	4958	766	2881	51.0	0.585
Kinhala	179	124	151	10.6	4931	817	2828	46.0	0.574
Bhugaon	165	121	142	9.2	3895	331	1797	64.3	0.365
Manori	153	119	136	6.6	1896	66	761	71.6	0.154
Takali	180	127	151	10.6	4938	579	2872	45.6	0.583
Talegaon	155	122	140	7.1	2935	367	1529	59.5	0.310
Wardha	171	122	146	9.6	4866	346	2003	69.7	0.407
Hatodi	149	120	136	5.9	2005	276	1024	53.9	0.208
Parseoni	160	124	142	7.7	3688	497	1875	54.7	0.381

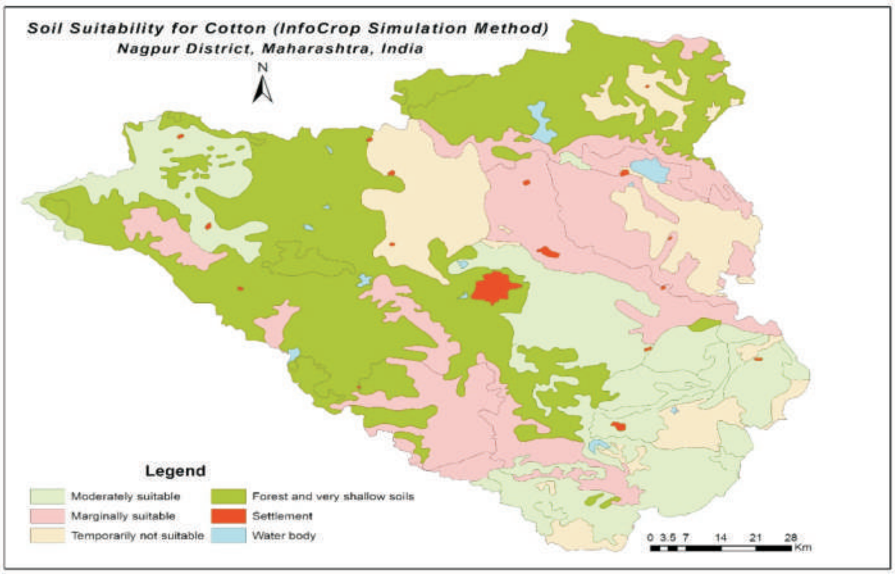

Fig. 4. Soil suitability map for rainfed hybrid cotton using InfoCrop simulation model

Table 5 provides a summary output of the three land evaluation techniques. Three soil series, *viz.*, Kinhala, Katol and Takali classified as marginally suitable in the qualitative simple limitation method were reclassified as moderately suitable in the semi-quantitative parametric technique. The corresponding high values of RYI obtained in the quantitative crop simulation output, from 0.574 to 0.585, corroborates this up-gradation. The lowest value of RYI, 0.154, observed in Manori series, also justifies its reclassification as currently unsuitable by the Storie Index method.

Table 5. Comparative performance of the three techniques of Land evaluation for rainfed cotton

	Simple limitation	Storie Index	InfoCrop model output	
Soil series	**Suitability Class**	**Suitability Class**	**Ratio of water-limited to potential yield**	**CV in yield (%)**
Kinhala	Marginally suitable	Moderately suitable	0.574	46
Katol	Marginally suitable	Moderately suitable	0.585	51
Talegaon	Marginally suitable	Marginally suitable	0.310	59.5
Hatodi	Marginally suitable	Marginally suitable	0.208	53.9
Wardha	Moderately suitable	Moderately suitable	0.407	69.7
Parseoni	Moderately suitable	Marginally suitable	0.381	54.7
Bhugaon	Moderately suitable	Moderately suitable	0.365	64.3
Takali	Marginally suitable	Moderately suitable	0.583	45.6
Manori	Marginally suitable	Currently unsuitable	0.154	71.6

Cotton is cultivated under diverse climatic conditions and a wide range of soils. However, majority of the rainfed cotton in Central India is grown in the shrink-swell soils, known as "Black Cotton Soils", represented by the Vertisols and Vertic Intergrades (Mandal *et al.* 2005). In the present study, five of the nine soil series selected were Vertisols; three were Inceptisols and only one series, Manori was an Entisol.

The essence of all land evaluation techniques is matching the land characteristics of the area with requirements for specific land use, presently for the cultivation of rainfed hybrid cotton. The efficacy of three land evaluation techniques to delineate and prioritise soils for cultivation of rainfed hybrid cotton was compared. In the Simple Limitation method, the land characteristic with the lowest rating determines the overall suitability of the soil (Davidson 1992); in this investigation, it was soil depth, soil pH and CEC (Table 2). The semi-quantitative parametric method of Storie Index allocated numerical ratings to the relevant land characteristics, *viz*, mean rainfall during the growing season, texture, soil depth, soil pH and CEC. These values were then combined into a composite numerical rating as the Land Index, which ranged from 20.3 in Mansori series to 55.3 in Wardha series (Table 3). Soils of Manori series with severe limitations of texture and depth were rated as marginally suitability by the Simple Limitation method and currently not suitable using Storie Index method. From earlier studies, it was found that Typic Ustorthents were marginally suitable, and Typic Haplusterts were moderately suitable for rainfed cotton (Ghode *et al.* 2018).

Quantitative land evaluation using Infocrop model provided numerical estimates of yield for the different soil series. The potential yield (4927 kg ha^{-1}), is a function of the genetic potential of the variety, radiation, day length and temperature regime (Van Ittersum *et al.* 2013). Since genetic coefficients of the variety and atmospheric CO_2 concentration were kept constant during simulation, the potential yield is not expected to vary over the years, and hence the CV was low, *i.e.,* 1.4%. The wide variation in rainfed (water-limited) yields from 761 to 2881 kg ha^{-1} represents the combined effects of varying soil characteristics of different soil series with the rainfall pattern on cotton productivity. Unlike the other two land evaluation methods, the simulation model approach utilised the actual daily weather data for each year of simulation. The coefficient of variation in water-limited yields, ranging from 46% in Kinhala to 76.6% in Manori series, reflects the risk involved in growing rainfed cotton in the areas with an erratic distribution of rainfall over the years. Seasonal rainfall, soil hydraulic conductivity and variation in plant-available soil moisture were the main factors contributing to variations in rainfed crop yields in cracking clay soils (Russel 1984; Kadu *et al.* 2003; Deshmukh *et al.* 2014).

The values of RYI ranged from 0.154 in Manori to 0.585 in Katol series. Based on RYI, the ranking of soils, in decreasing order of suitability for rainfed cotton, was Katol > Takali > Kinhala > Wardha > Parseoni > Bhugaon > Talegaon > Hatodi > Manori. In general, Typic Haplusterts and Typic Haplustepts were more suitable than Lithic Haplustepts and Typic Ustorthents. The benchmark soils of Black soil region of India were ranked based on RYI for rainfed cotton production, and it was reported that RYI could capture suitable differences in soil characteristics and weather patterns on rainfed cotton yields (Venugopalan *et al.* 2014).

Both the qualitative Simple Limitation method and the semi-quantitative method of Storie Index delineated the soils based on the number and degree of limitation for the cultivation of rainfed hybrid cotton. However, in these methods, the extreme values of land characters would have a bearing on the overall suitability rating and maybe underestimated (Davidson 1992; Vargahan *et al.* 2011). In the present study, all the soils are rated as marginally or moderately suitable or currently not suitable, that may be an underestimate. Additionally, these methods also do not consider the interaction effects among land characteristics in modifying the overall suitability. The soil depth (<35 cm) was the major limitation in Talegaon, Hatodi and Manori series. However, unlike Manori, a higher clay content in Talegaon series helped to store more soil water and support rainfed cotton better than the Manori series resulting in a slightly higher RYI of a 0.310. Based on the present assessment, soils of Hatodi and Manori series are not ideal for the cultivation of rained hybrid cotton.

Unlike Simple Limitation and Storie Index methods, InfoCrop simulation model quantified the performance of cotton in terms of yield, crop duration, evapotranspiration, soil water balance and other biophysical factors by integrating all the soil and climatic parameters involved in cotton production and appeared to be more realistic. Although the evaluation using RYI can be performed for any parcel of land, the model must be calibrated and validated before its actual use. Detailed information, on soil, weather, crop variety and management practices are a prerequisite for simulation.

Conclusion

The quantitative land evaluation using InfoCrop model was data exhaustive, but the outputs were superior to the Simple Limitation method and the semi-quantitative method of Storie Index. The InfoCrop model approach provides the nature, degree and numerical values of the suitability of soils for hybrid cotton and its possible effect on productivity by integrating the soil and climatic factors. The soils of Katol, Kinhala and Takali soil series are relatively more suitable than the other soils for cultivation of rainfed hybrid cotton. Soils of Hatodi and Manori series are not suitable for cultivation of rainfed hybrid cotton. Moreover, the model can be employed to evaluate the effects of management interventions to overcome these limitations. These land evaluation techniques are universal and can be employed globally for soil suitability analysis.

References

Aggarwal, P.K., Kalra, N., Chander, S. and Pathak, H. (2006). Infocrop: A dynamic simulation model for the assessment of crop yields, losses due to pests, and environmental impact of agro-ecosystems in tropical environments. I. Model description. *Agriculture System* **89**, 1-25.

Anderson, L.T. (1987). Seven methods for calculating land capability/suitability, Planning Advisory Service (PAS), Report No. 402. Chicago, USA: American Planning Association.

Challa, O., Gajbhiye, K.S. and Velayutham, M. (1999). Soil Series of Maharashtra. NBSS Publication No 79, NBSS&LUP, Nagpur, pp. 428.

Davidson, D.A. (1992). The evaluation of land resources. Longman Scientific & Technical. University of Michigan, Michigan, pp. 198.

De La Rosa, D. and Van Diepen, C.A. (2002). Qualitative and quantitative land evaluation. In '1.5. Land Use and Land Cover, in Encyclopedia of Life Support System (EOLSS-UNESCO) (Eds. W. Verheye), Developed under the Auspices of the UNESCO. EOLSS Publishers, Paris, France. (http://www.eolss.net).

Deshmukh, H., Chandran, P., Pal, D.K., Ray, S., Bhattacharyya, T. and Potdar, S. (2014). A pragmatic method to estimate Plant Available Water Capacity (PAWC) of rainfed cracking clay soils (Vertisols) of Maharashtra, Central India. *Clay Research* **33,** 1-14

FAO (1976). A Framework for Land Evaluation. FAO Soils Bulletin 32, FAO, Rome, Italy.

Ghode, M.K., Vaidya, P.H., Dhawan, A.S. and Adkine, S.A. (2018). Characterisation, classification and evaluation of cotton growing soils of Nanded District, Maharashtra. *Journal of Pharmacognosy Phytochemistry Special Issue* **1**, 1221-1225.

Hebbar, K.B., Venugopalan, M.V., Seshasai, M.V.R., Rao, K.V., Patil, B.C., Prakash, A.H., Kumar, V., Hebbar, K.R., Jeyakumar, P., Bandhopadhyay, K.K., Rao, M.R.K., Khadi, B.M. and Aggarwal, P.K. (2008). Predicting cotton production using Infocrop-cotton simulation model, remote sensing and spatial agro-climatic data. *Current Science* **95,** 1570-1579.

Hebbar, K.B., Venugopalan M.V., Prakash A.H. and Aggarwal, P.K. (2013). Simulating the impacts of climate change on cotton production in India. *Climate Change* **118,** 701-713.

Hopkins, L.D. (1977). Methods of generating land suitability maps: A comparative evaluation. *Journal of American Institute of Planners* **43**, 386–400.

Kadu, P.R., Vaidya, P.H., Balpande, S.S., Satyavathi, P.L.A. and Pal, D.K. (2003). Use of hydraulic conductivity to evaluate the suitability of Vertisols for deep-rooted crops in semi-arid parts of Central India. *Soil Use and Management* **19**, 208–216.

Mandal, D.K., Mandal, C. and Venugopalan, M.V. (2005). Suitability of cotton cultivation in shrink-swell soils in central India. *Agricultural Systems* **84**, 55–75.

Manna, P., Basile, A., Bonfante, A., De Mascellis, R. and Terribile, F. (2009). Comparative land evaluation approaches: An itinerary from FAO framework to simulation modelling. *Geoderma* **150**, 367-378.

Naidu, L.G.K., Ramamurthy, V., Challa, O., Hegde, R. and Krishnan, P. (2006). Manual Soil-Site Suitability Criteria for Major Crops. NBSS Publ. No. 129, NBSS&LUP, Nagpur, pp. 118.

Rabia, A.H. and Terribile, F. (2014). Introducing a new parametric concept for land suitability assessment. *International Journal of Environmental Science and Development* **4**, 15-19.

Rossiter D.G. (2003). Biophysical models in land evaluation. In 'Encyclopedia of Life Support Systems (EOLSS) (Eds. Verheye, W.H.), ELOSS Publishers, Oxford, UK. (http://www.eolss.net).

Russel J.S. (1984). Management of cracking clay soils in rainfed environments. In 'The Properties and Utilisation of Cracking Clay Soils (Eds. J.W. Mcgarty, E.H. Hoult and H.B. SO), Reviews in Rural Science V, University of New England, Australia, pp. 317-325.

Steiner, F. (1987). Agricultural land evaluation and site assessment in the United States: An introduction. *Environtal Management* **11**, 375-377.

Storie, R.E. (1978). Storie Index Soil Rating. Special Publication 3203, Division of Agricultural

Sciences, University of California, Berkeley, California.

Sys, C., Van Ranst, E. and Debaveye, J. (1991). Land Evaluation. Part I: Principles in land evaluation and crop production calculations. Agricultural Publication No. 7., General Administration for Development Cooperation, Brussels, Belgium.

Van Ittersum, M. K., Cassman, K. G., Grassini, P., Wolf, J., Tittonell, P. and Hochman, Z. (2013). Yield gap analysis with local to global relevance - A review. *Field Crops Research* **143,** 4-17.

Van Lanen, H.A.J., Van Diepen, C.A., Reinds, G.J. and De Koning, G.H.J. (1992). A comparison of qualitative and quantitative physical land evaluations, using an assessment of the potential for sugar - beet growth in the European Community. *Soil Use and Management* **8**, 80-89.

Vargahan, B., Shahbazi, F. and Hajrasouli, M. (2011). Quantitative and qualitative land suitability evaluation for maize cultivation in Ghobadlou Region, Iran. *Ozean Journal of Applied Sciences* **4,** 1943-2429.

Venugopalan, M.V., Reddy, A.R., Kranthi, K.R., Yadav, M.S., Satish, V. and Pable, D. (2017). A Decade of Bt Cotton in India: Land Use Changes and Other Socio-Economic Consequences. In 'Sustainable Management of Land Resources- An Indian Perspective' (Eds. G.P. Obi Reddy, N.G. Patil and A. Chaturvedi), pp. 669-698. (Apple Academic Press, New Jersey).

Venugopalan, M.V., Tiwary, P., Hebbar, K. B., Ramamurthy, V., Chatterji, S., Rao, K.V., Sen, T.K., Deshmukh, H.V. and Wahane, M.R. (2007). Evaluation of INFOCROP-cotton model in some shrink-swell soils under rainfed conditions. *Agropedology* **17,** 34-40.

Venugopalan, M.V., Tiwary, P., Ray, S.K., Chatterji, S., Velmourougane, K., Bhattacharyya, T. (2014). InfoCrop-cotton simulation model – its application in land quality assessment for cotton cultivation. *Current Science* **107**, 1512-1518.

Wu, D., Yu, Q., Lu, C. and Hengsdijk, H. (2006). Quantifying production potentials of winter wheat in the North China Plain. *European Journal of Agronomy* **24,** 226–235.

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