Agropedology 2009, 19 (1), 57-62

Modeling soybean yield in different types of soils of Udaipur district, Rajasthan – A case study

ADITYA KUMAR SINGH, R. S. SINGH AND S.P.S. TANWAR[1]

National Bureau of Soil Survey and Land Use Planning, Regional Centre, Udaipur-313 001, India
[1] Central Arid Zone Research Institute, Regional Research Station, Pali-306 401, India

Abstract : The study was conducted for the evaluation of soil suitability criteria for soybean crop in Udaipur district (AESR 4.2) of Rajasthan. Ten farmers' fields were selected with varying soil texture, depth and slope. The yield was monitored consecutively for three years during *kharif* season of 2004, 2005 and 2006. Based on yield data of 2004, multivariate regression model was developed to relate crop production to six independent variables. By using the regression equation, yield was predicted in 2005 and 2006 which was compared with actual yield. Shallow, moderately shallow and sandy loam soils were not suitable for growing soybean crop whereas deep clay loam and clay soils were suitable. Besides AWC, management factors *viz.* hoeing, weeding and plant population also played important role in influencing crop yield. The simulation of spatially distributed soybean yields was strongly affected by the soil variability within the region.

Additional key words: *Crop modeling, soil suitability, soil water availability, soybean yield*

Introduction

Site-specific soil management is the process of managing soils based on localized conditions within field boundaries which affect crop yield. To be effective, management schemes must address both soil variability and soil properties limiting yield. Soil variability is caused by an assortment of different factors. Interactions among parent materials, topography, vegetation, tillage, fertilization, cropping history, *etc.* can cause variations in physical and chemical properties of soils in the field.

Soybean is one of the major crops in Rajasthan occupying 42.9 % area of kharif oilseeds. However, its productivity is low (1180 kg ha^{-1}) in Udaipur district as well as at state level (1425 kg ha^{-1}) (Govt. of Rajasthan 2007). It is, therefore, essential to validate production potential of available land and to identify the constraints for suggesting the proper land use according to its capability and/or suitability. In view of the above, three sites in Udaipur district were selected to develop a yield prediction model for soybean crop and evaluation of soil suitability criteria.

Materials and Methods

The study area lies in Udaipur district with three sites at Changeri, Vana and Navania. It represents hot, dry, semi-arid (Aravali East Upland) AESR 4.2 and receives rainfall between 500 and 600 mm, with potential evapo-transpiration (PET) of 1380 mm. The rainfall received during 2004, 2005 and 2006 was 480, 544 and 789 mm, respectively. Typifying pedons were exposed and morphological characteristics were described (Soil survey staff 1995) at selected farmers' fields. Horizon-wise samples were collected and processed for laboratory investigation (Sparks *et al.* 1996; Jackson 1973) and the soils were classified. The water retention analysis was done by using pressure plate apparatus (Richards 1954). Crop suitability for soybean was evaluated by matching soil- site characteristics with crop requirements using FAO approach (1976) and modified suitability criteria of Sys *et al.* (1991) and Jain *et al.* (2000). Limitations were assessed on the basis of productivity at given level of individual parameters (Verheye 1996) as suitable (85%), moderately suitable (60%), marginally suitable (40%) and not suitable (<40%). For developing the regression model, the weightages were assigned (0.10 to 0.75) to variables affecting the soybean yield (Sys *et al.*, 1991). The highest numerical value was assigned for contribution of each variable towards maximum soybean production. Similarly, the lowest value was assigned for lowest yield obtained by each factor (Table 1). With increasing depth and texture, the AWC was increased and hence higher yield was obtained at Navania where maximum ratings were assigned. Irrigation during long dry spells was essential for obtaining potential yield of soybean crop as it can withstand waterlogging conditions but it can not withstand water shortage at dry spells. Similarly, field leveling and management also played important role in affecting yield and accordingly weightage was assigned. For evaluation, 10 farmers' fields were selected at three referred sites with different soil textures, depths (30 to >100 cm) and slope (1-3% to 3-8%). The soil samples were drawn for determining soil-moisture content at fortnight intervals from 0-15, 15-30, 30-50 and 50-80 cm depth of soil in the fields. The yield was monitored continuously for 3 years during kharif seasons of 2004, 2005 and 2006.

A multiple regression model was developed to relate soybean crop production to a set of outlined independent variables, which is the direct extension of polynomial regression equation of one independent variable (Eq.1).

Soybean crop predicted yield (q/ha) =

$\beta0+ \beta1x1+ \beta2x2+\beta3x3+ \beta4x4+ \beta5x5+\beta6x6$ ------- (Eq. 1)

Where $\beta0$ = intercept, $\beta1$ = soil depth (cm), $\beta2$ = soil texture, $\beta3$ = AWC, $\beta4$ = irrigation, $\beta5$ = field levelling and $\beta6$ = management.

Table 1. Weightages assigned to different factors influencing soybean yield

Field No.	Depth	Texture	AWC	Irrgation	Field levelling	Management
			Changeri site			
1	0.30	0.50	0.40	0.20	0.40	0.20
2	0.50	0.50	0.55	0.50	0.50	0.40
3	0.70	0.60	0.60	0.60	0.60	0.65
4	0.70	0.65	0.70	0.20	0.50	0.40
			Vana site			
5	0.70	0.60	0.65	0.60	0.50	0.60
6	0.70	0.60	0.65	0.60	0.70	0.65
7	0.70	0.70	0.70	0.70	0.75	0.70
			Navania site			
8	0.75	0.75	0.75	0.20	0.40	0.40
9	0.75	0.75	0.75	0.75	0.75	0.75
10	0.75	0.75	0.75	0.75	0.70	0.70

Regression equation for predicting yield was developed from the data collected in 2004 and prediction was done for the season 2005 and 2006.

Results and Discussion

Soils and soil moisture availability

At Changeri site (Table 2), soils (Loamy, mixed, hyperthermic Lithic Haplustepts) were characterized as shallow, dark brown, well drained, moderately alkaline, sandy loam at the surface and sandy clay loam in the sub-surface situated on partially cemented carbonate rich Ckm horizon. Moderately shallow soils (Typic Haplustepts) were dark brown, well drained, calcareous, strongly alkaline with loamy surface, sandy clay loam to clay loam sub-surface underlain by partially weathered C

Table 2. Important properties of soils of selected sites

Horizon (cm)	Total depth (cm)	Clay (%)	$CaCO_3$ (%)	Soil moisture (%) 33 kPa	Soil moisture (%) 1500 kPa	pH	EC dSm^{-1}	Org. C. (%)
				Changeri site				
0-15	<50	12.6	3.65	9.8	4.4	8.00	0.10	0.46
15-30		15.7	3.42	11.2	5.0	8.20	0.07	0.35
0-15	65-70	17.4	1.73	12.2	5.0	8.03	0.11	0.47
15-30		17.3	1.81	12.9	5.1	7.92	0.14	0.38
30-50		20.2	1.92	13.6	5.7	8.10	0.09	0.30
50-70		20.6	1.99	14.0	6.1	8.12	0.10	0.25
0-15	85-90	20.2	3.46	15.1	6.6	8.54	0.13	0.62
15-30		22.1	3.76	16.8	7.2	8.37	0.18	0.38
30-50		26.5	3.85	22.6	10.4	8.37	0.20	0.35
50-80		26.9	3.95	23.0	10.8	8.51	0.20	0.30
0-15	100	21.9	4.88	24.1	11.7	7.80	0.30	0.49
15-30		22.6	3.11	25.1	12.9	8.30	0.20	0.42
30-50		30.1	3.23	30.1	16.9	8.43	0.24	0.35
50-80		31.0	3.54	31.5	17.0	8.83	0.27	0.29
				Vana site				
0-15	85-90	31.3	3.15	27.6	13.6	8.62	0.36	0.50
15-30		32.2	5.49	30.8	15.4	9.00	0.42	0.46
30-50		35.7	5.21	30.9	16.0	9.12	0.43	0.38
50-80		39.6	5.56	34.3	18.1	9.05	0.42	0.31
0-15	100	32.3	3.46	28.3	14.4	8.52	0.28	0.56
15-30		33.5	3.76	30.2	16.1	8.82	0.23	0.46
30-50		35.9	3.85	31.5	16.5	9.00	0.29	0.34
50-80		40.1	3.96	34.9	18.3	9.11	0.37	0.25
0-15	100	39.7	7.80	31.2	17.0	9.00	0.29	0.59
15-30		41.2	8.07	32.2	18.2	9.12	0.37	0.48
30-50		41.5	8.50	35.2	18.7	9.14	0.40	0.32
50-80		41.9	8.11	35.9	18.9	9.16	0.41	0.26
				Navania site				
0-15	>100	42.9	6.69	32.8	17.5	7.97	0.31	0.63
15-30		45.8	6.52	34.3	18.0	8.54	0.19	0.52
30-50		44.5	6.74	34.4	18.2	8.69	0.22	0.40
50-80		44.5	6.85	34.6	18.3	8.77	0.21	0.38
0-15	>100	45.2	6.34	35.6	19.2	7.88	0.43	0.65
15-30		48.8	6.92	37.1	20.3	8.61	0.24	0.47
30-50		49.5	7.02	37.8	20.4	8.88	0.28	0.38
50-80		49.6	7.13	37.9	20.6	8.98	0.31	0.31
0-15	>100	49.6	7.11	36.0	19.6	8.76	0.33	0.55
15-30		52.7	6.92	38.7	20.6	8.82	0.43	0.47
30-50		53.3	6.95	39.1	21.0	8.85	0.35	0.37
50-80		53.2	6.75	39.3	21.1	8.89	0.38	0.28

horizon. The other soils (Typic Haplustepts) were deep to very deep, well drained, moderately alkaline with dark brown loamy surface horizons and strongly alkaline and dark yellowish brown, sandy clay loam sub-surface horizons. At Vana site, shallow and moderately deep (Typic Haplustepts) fine soils occur on gently sloping plains. These soils had higher clay content with interspersed monadnocks and were moderately eroded, well drained, moderately saline and slightly sodic in nature. At Navania site, the soils (Typic Haplustepts)

Table 3. Predicted and observed yields of soybean at the selected sites

Soil depth (cm)	Yield ($q^{-1}ha$)								
	2004			2005			2006		
	Number of irrigations	Observed	Predicted	Number of irrigations	Observed	Predicted	Number of irrigations	Observed	Predicted
Changeri site									
<50	0	3.5	3.46	1	7.8	7.35	0	2.1	2.39
65-70	1	9.3	9.07	1	10.5	10.90	1	8.5	8.91
85-90	1	13.5	13.45	1	21.9	19.78	1	22.0	21.46
>100	0	7.4	7.76	1	20.3	19.48	1	15.6	16.65
Vana site									
85-90	1	12.5	12.95	1	15.1	14.78	1	11.5	12.38
>100	1	16.2	15.55	1	18.2	18.38	1	15.5	14.56
>100	1	20.1	21.50	1	20.2	20.58	0	18.6	19.21
Navania site									
>100	0	9.4	9.13	0	12.5	12.78	0	13.8	14.20
>100	1	24.5	23.94	1	25.0	25.35	1	25.6	26.11
>100	1	22.5	22.60	1	22.3	22.60	0	18.9	19.47

occurring on very gently sloping plains with interspersed monadnocks were deep with clayey surface, moderately eroded, well drained, moderately saline and slightly sodic in nature. The $CaCO_3$ content increased with depth and it was the highest in clayey soils. Higher organic carbon content and lower soil pH values were noticed in surface as compared to sub-surface horizons. In shallow soils, low EC was recorded. At Changeri site, clay content in shallow, moderately deep and deep soils ranged from 12.6-15.7, 17.4-17.3 and 21.9-22.6 per cent, respectively. The soil moisture in deep soils with clay content of 21.9-31.0 per cent was 24.1-31.5 per cent (33 kPa) to 11.7-17.0 per cent (1500 kPa). At Vana site, clay content ranged from 31.3-41.9 per cent and AWC from 27.6-35.9 per cent (33 kPa) to 13.6-18.9 per cent (1500 kPa). In deep clay soils (clay 42.9-53.2%) at Navania site and the maximum soil moisture range of 32.8-39.3 per cent (33 kPa) to 17.5-21.1 per cent (1500 kPa) were observed (Table 2).

Multilinear regression model

A multilinear regression model was developed for predicting the soybean yield. Factors which have significant correlation with soybean yield i.e. soil depth, texture, AWC, irrigation, field leveling and management were chosen for regression model. These were individually significant at 5 per cent level of significance. These factors account for 99 % variations in soybean yield.

For soybean yield ($q^{-1}ha$)

Y = -18.9611-28.2587 (soil depth, mm) + 23.63523 (soil texture) + 25.18136 (AWC) + 9.932669 (irrigation) + 8.412177 (field leveling) + 18.29615 (management).

The soybean yield model was developed from the data collected in 2004 and performance of the model was tested in 2005 and 2006.

Effect of soil moisture on yield in different types of soils

At Changeri, it was observed that shallow (<50 cm) sandy loam soils were not suitable for growing soybean crop (2.1-7.8 qha^{-1}) (Table 3) owing to lower water holding capacity. The moderately shallow (65-70 cm) sandy loam soils yielded 8.5-10.5 qha^{-1}. The reason for low yield in these soils was low soil moisture availability (1000-1500 kPa) in the root zone at pod development

Table 4. Soil moisture availability during crop growing period of soybean during kharif, 2006

Soil depth (cm)	Horizon (cm)	Irrigation	Soil moisture (%) in kPa at 15 days interval						
			Vegetative growth phase			Pod development stage			Maturity phase
<50 (Changeri)	0-15	-	5.5	9.8	9.7	5.2	3.0	8.8	2.5
	15-30		6.7	11.1	10.6	6.7	3.3	10.5	6.1
	30-50		7.0	10.2	10.7	6.6	3.1	11.5	6.8
65-70 (Changeri)	0-15	I	17.9	16.1	18.9	8.9	14.1	9.0	7.1
	15-30		17.1	15.2	17.1	12.3	14.9	9.8	8.0
	30-50		17.2	16.6	16.0	13.3	15.1	11.6	10.2
	50-70		17.3	18.5	17.1	16.0	15.5	14.3	11.5
100 (Changeri)	0-15	I	20.5	28.3	25.7	22.0	16.3	14.5	11.8
	15-30		20.8	27.4	24.8	22.8	17.1	15.8	13.0
	30-50		21.9	25.9	25.8	23.8	20.0	19.4	17.0
	50-80		21.5	23.7	25.3	25.2	21.2	19.9	17.2
>100 (Navania)	0-15	I	20.6	36.1	33.0	26.4	30.9	26.0	22.1
	15-30		20.7	31.4	28.7	27.8	28.6	27.5	22.8
	30-50		22.6	28.4	27.6	27.0	28.4	28.5	23.5
	50-80		24.3	28.3	27.2	26.8	28.2	28.0	26.1

stage (Table 4). Even the deep sandy loam soils produced low yield of 7.4 qha^{-1}, although water was not available at the pod development stage. When irrigation was given at the time of water shortage (pod development stage), there was a good yield of 20.3 qha^{-1} (2005) in these soils. There were dry-spells of 25 days (2004), 19 days (2005) and 17 days (2006) during pod development stage. In these years, the rainfall was 382 mm (2004), 366 mm (2005) and 517 mm (2006), respectively. During pod development, the rainfall received was 29 mm (2004), 112 mm (2005) and 55 mm (2006), respectively. During 2006, due to continuous rains at vegetative stage, farmers were not able to do hoeing and weeding operations which resulted in low yield of 15.6 qha^{-1}. At Vana site, the clay loam soils produced higher yield (20.1 qha^{-1}) due to higher AWC and better management. Similar findings were also reported by Bhaskar *et al.* (1996) and Wadodkar *et al.* (1996). At Navania site, deep clay soils (due to higher AWC), even without irrigation, produced 9.4-18.7 qha^{-1} grain (Table 4). An additional irrigation at crucial pod development stage increased the yield to 22.5-25.6 qha^{-1}. Similar results were also reported by Lomte *et al.* (2006). Cox *et al.* (2003) also opined that areas with higher clay content had higher grain yield suggesting clay could be an important parameter in site-specific soil management.

Deriving soybean yield response from simulation results

On the basis of 2004 yield data (Table 3), the regression model was developed. The predicted yield values in individual years were within acceptable limits with more or less even distribution of difference from observed crop yield and the crop yield is largely governed by variables considered in model. These relationships take the form of climate-specific regressions between a soil indicator and average yields. The selected soil indicator was available water capacity (AWC). AWC was calculated up to 0.80 m depth, since it corresponds to the maximum depth at which annual plant roots can go. Similar types of results were also observed by Wassenaar *et al.* (1999) where they got strong relationship between average wheat yield and AWC over the period 1977–1984.

References

Bhaskar, K.S., Gaikawad, S.T. and Anantha Rao, D. (1996). Soil-site suitability evaluation for wheat - A case study. *Agropedology* **6**, 89-94.

Cox, M. S., Gerard, P. D., Wardlaw, M. C. and Abshire, M. J. (2003). Variability of selected soil properties and their relationships with soybean yield. *Soil Science Society of America Journal* **67**, 1296-1302.

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

Govt. of Rajasthan. (2007). Vital Agricultural Statistics 2004-05. Directorate of Agriculture, Rajasthan, Jaipur (Statistical cell), 138 pp.

Jackson, M.L. (1973). Soil Chemical Analysis of India. Prantice Hall of India Ltd., New Delhi. 496 pp.

Jain,B.L., Singh, R.S., Shyampura, R.L. and Velayutham, M. (2000). Agro-ecological assessment of soil resources of Rajasthan for land use planning. *NBSS Bulletin No.* 81. NBSS&LUP, Nagpur. 88 pp.

Lomte, D.M.; Umate, M.G.; Kagade, N.V. and Kausale, S.P. (2006). Soil moisture studies in different soybean (*Glycine max* (L)Merrill) genotypes in relation to land configuration treatments. *Journal of Oilseeds Research* **23**, 115-116.

Richards, L.A. (1954). Diagnosis and Improvement of Saline and Alkali Soils. USDA Agriculture Handbook No.60. Washington, D.C. 160 pp.

Soil Survey Staff (2003). Keys to Soil Taxonomy. United States Department of Agriculture, Ninth Edition, Washington, USA. 332 pp.

Sparks, D.L., Page, A.L., Helenke, P.A., Loeppert, R.H., Soltanpour, P.N., Talbatabai, .A., Johnston, C.T. and Sumner, M.E. (1996). Methods of Soil analysis. Part III. Soil Science Society of America, Madison, Wisconsin, USA.

Sys,C., Van Raust, E. and Debaveye, J. (1991). Land evaluation, Part I-III. ITC and State University of Ghent Agricols. 274 pp.

Verheye, W.H. (1996). Rating and definition of suitability classes. FAO approach for land evaluation. *Agropedology* **6**, 1-12.

Wadodkar, M.R., Sehgal, J and Challa, O. (1996). Soil Site suitability for soybean in Vidharbha region. *Agropedology* **6**, 95-101.

Wassenaar, T, Lagacherie, P., Legros, J.P. and Rounsevell, M.D.A. (1999). Modelling wheat yield responses to soil and climate variability at the regional scale. *Climate Research* **11**, 20-220.

Received on : October 2007, Accepted on : June 2008