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Assessment of Influence of Soil-site Characteristics on Soybean Productivity in Swell-shrinks and Associated Soils of Semi-arid Tropics

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ABSTRACT: A study has been conducted in swell-shrink and associated soils to assess the influence of soil-site characteristics on rainfed soybean yield attained with low and improved management practices across four microwatersheds viz., Varkhed and Panubali in Maharashtra; and Jaitpura and Khuj in Madhya Pradesh. There was a wide spatial variability of soil-site characteristics of swell-shrink and associated soils viz., Typic Ustorthents, Typic Haplustepts, Vertic Haplustepts, Typic Haplusterts within and across four microwatersheds. In general, soybean productivity was high in Typic Haplusterts followed by Vertic Haplustepts while it was low with Typic Ustorthents under both management levels. Based on correlation and regression analysis, the most important soil-site characteristics influencing soybean yield were found to be drainage among site characteristics; soil depth and AWC among soil physical, and OC and CEC among soil chemical characteristics. The study indicated that for improving the productivity of rainfed soybean cultivated in swell-shrink and associated soils, soil depth, AWC, OC and CEC with ideal conditions were essential for attaining a yield level of 7-8 q ha^{-1} with low management, while only two soil characteristics viz., soil depth and AWC were found important for attaining a yield level of 12-14 q ha^{-1} with improved management.

Key words: Swell-shrink and associated soils, soil-site characteristics, regression modeling, soybean productivity.

Soybean is an important crop and extensively grown in swell-shrink and associated soils (shallow, medium and deep black soils) under rainfed condition in semi-arid parts of Vidarbha region of Maharashtra, Malwa plateau and Baghelkhand region of Madhya Pradesh. Swell-shrink and associated soils occupy nearly 72 M ha in India and are grouped taxonomically under Entisols, Inceptisols and Vertisols. Variation in growth and yield of soybean grown on these soils are mainly attributed to soil-site characteristics (Shivaramu *et al.,* 1998). Therefore, systematic field studies are essential for interpretation and quantification of soil characteristics on the productivity of soybean. Keeping this in view, field studies were undertaken in swell-shrink and associated soils across four microwatersheds in Maharashtra and Madhya Pradesh.

Materials and Methods

Field experiments were undertaken (under NATP-MM-LUP-III/ 28 - Rainfed Agroecosystem Project), to study impact of soil-site characteristics under two management levels during two rainy cropping seasons (2003-04) on 12 varying soil units in four microwatersheds in Maharashtra and Madhya Pradesh states *viz.,* Varkhed BK Watershed (Barshitkali Tehsil, Akola district, Maharashtra State, Longitude: 77^0 7'00" to 77^0 10' 00" E, Latitude:20^0 32' 30" to 20^0 35' 00" N, Altitude:325 m above MSL); Jaitpura watershed (Indoor district, Madhya Pradesh, Longitude: 75.51^0 E, Latitude: 22.51^0 N, Altitude:565 above MSL); Panubali watershed (Kalmeshwar tahsil, Nagpur district, Maharashtra State, Longitude: $78^0$51'E, Latitude: 21^0 20'N, Altitude: 350 m above MSL) and Khuj microwatershed, Banga Nala watershed (Block Raipur (Karchulian) Rewa district, Madhya Pradesh, Longitude: $81^0$24' 00" to $81^0$31' 00" E, Latitude: 24^0 30' 45" to 24^0 37' 15" N).

Before experimentation, the detailed soil survey was conducted in all the four microwatersheds as per the procedure outlined in Soil Survey Manual (IARI, 1971). Majorily, soils under study were qualified under Entisols, Inceptisols and Vertisols and were classified as: Varkhed-a: Loamy, mixed, non calcareous hyperthermic Typic Ustorthents; Varkhed- b: Very fine, smectitic, (calcareous), hyperthermic Vertic Haplustepts; Varkhed - c: Very fine, smectitic, calcareous, hyperthermic Typic Haplusterts in Varkhed watershed; Jaitpura-a: Loamy-skeletal, mixed, non calcareous hyperthermic Lithic Ustorthents, Jaitpura- b: Fine, mixed, calcareous, hyperthermic Vertic Haplustepts, Jaitpura- c: Very fine, smectitic, calcareous, hyperthermic Typic Haplusterts in Jaitpura watershed, Panubali-a: Fine-loamy, mixed, hyperthermic Typic Haplustepts, Panubali-b: Fine, smectitic, hyperthermic (calcareous), Vertic Haplustepts, Panubali-c: Fine, smectitic, hyperthermic (calcareous), Typic Haplusterts in Panubali watetrshed and Khuj-a: Fine loamy, mixed hyperthermic Typic Haplustepts, Khuj-b: Fine loamy, mixed, hyperthermic Vertic Haplustepts and Khuj-c:Fine, smectitic, hyperthermic Typic Haplusterts.

The site characteristics *viz.* erosion and drainage after judging their extent as per the manual (with slight modifications to drainage ratings), were numerically rated for statistical analysis like nil to slight erosion as one, moderate as two, severe as three and very severe as four; poorly drained as one, imperfectly drained as two, moderately well drained as three, well drained as four and somewhat excessively drained as five. The physical and chemical properties (Table 1) of the profiles vis-a vis soil units were analyzed using standard procedures and then arrived at single weighted average values for each soil unit.

There were two levels of management in soybean experiments taken on each soil unit viz., low management (LM) which was similar to the local cultivation practices adopted by farmers and improved management level (IM) which was as per the package of cultivation practices recommended by the respective agricultural universities for rainfed soybean. Improved management (IM) practices at Varkhed and Panubali include: seed rate of 100 kg $ha^{-1,}$ seed treatment with Rhizobium japanicum @ 5 g/kg of seed, spacing (37.5 x 15 cm^2), fertilizer dose of 25 kg N ha^{-1} and 50 kg P_2O_5 ha^{-1}as basal, two hoeings (15 and 30 DAS), one hand weeding (20 DAS) and need based plant protection measures; at Jaitpra watershed, the IM practices include: seed rate of 80-100 kg ha^{-1}, seed treatment with Thiram + Bavistin 1:1 ratio @ 3 g/kg of seed, inoculation with Rhizobium japanicum @ 5 g/kg of seed, spacing of 30 x 3-5 cm^2 fertilizer dose of 30 - 40 kg N ha^{-1} and 60 kg P_2O_5 ha^{-1} and 20 kg K_20 ha^{-1} as basal, two intercultural operations with small harrow (18-20 DAS and 35 DAS) and need based plant protection measures and at Khuj watershed, the Im practices include seed rate of 100 kg ha^{-1}, seed treatment with Thiram + Bavistin 1:1 ratio @ 3 g/kg of seed, inoculation with Rhizobium japanicum @ 5 g/kg of seed, spacing of 30 x 3- 5 cm^2 fertilizer dose of 20 kg N ha^{-1} and 40 kg P_2O_5 ha^{-1} as basal, two intercultural operations with small harrow (18-20 DAS and 35 DAS) and need based plant protection measures. Under low IM practices at all locations, the variety would be same, however the seed rate, spacing, fertilizer dose and other intercultural operations vary. The seed yield per hectare was calculated from the sun-dried seed weights of harvested net plots.

Estimates of correlation were measured between different soil-site characteristics and yield attained under low management, improved management and mean of both management levels (Gomez and Gomez, 1985). The effect of soil-site characteristics on yield was assessed based on linear and quadratic regression models. The suitability of soil characteristics was assessed based on the yield predictability, prediction error or the unexplained variation and the rate of change of yield for a unit change in the soil-site characteristics (Draper and Smith, 1988). The significantly influencing soil-site variables were identified and used for calibrating a multiple regression model. The soil-site variables, which were significant either in the individual regression models or jointly in the multiple regression models, have been identified for predicting soybean in swell-shrink soils across four microwatersheds.

Results and Discussion

Across four microwatersheds, 14 soil – site characteristics were studied for interpretation and quantification for soybean productivity. Among the soil-site characteristics, slope, erosion and drainage measured for, there was a variation of 35.1% for slope, 47.1% for erosion and 34.2% for drainage. In case of soil physical characteristics, a minimum variation of 13 per cent existed for silt and 13.5% for BD followed by 24.4% for clay, 37.7% for AWC, 44.2% for depth, while a maximum variation of 71% observed for sand at different sites. Among soil chemical characteristics, $CaCO_3$ showed a maximum variation of 127.6 % over different locations followed by OC (70 %). The yield attained with low management is in a range of 5. 30-to 11.19-q ha^{-1} with variation of 20.30 per cent compared to a higher yield of 5.50-to 19.67-q ha^{-1} with improved management with a relatively higher variation of 33.7 per cent. It is observed that Panubali-a recorded minimum yield (5.15 ha^{-1}) while Khuj-c recorded highest yield (15.43 ha^{-1}) in the study. The data indicated that there is a large spatial variability of swell-shrink and associated soils, under soybean cultivation, in respect of soil-site characteristics even within a microwatershed and across the watersheds in semiarid tropics.

Relationship of soybean yield with soil-site characteristics

Among the swell-shrink and associated soils (Table 1), there were significant differences in yield of soybean. In general, the soil unit belonging to the order Vertisols yielded high followed by Inceptisols while low productivity was observed in Entisols. At the sub-group level, the productivity potential of soils in descending order were Typic Haplusterts (Varhed–c, Jaitpura-c, Panubali-c, Khuj-c) followed by Vertic Haplustepts (Varkhed-b, Jaitpra-b, Panubali-b and Khuj-b) Typic Haplustepts (Jaitpra-b, Panubali-b and Khuj-b) and Typic Ustorthents (Varkhed-c). In a similar study, Chary *et al.* (1995) reported the low soybean yield potential of Typic Ustorthents and Typic Ustochrepts compared to Vertic Haplustepts and a high yield potential of Typic Haplusterts. The estimates of correlation coefficients of yield with different management levels with soil-site characteristics (Table 2) revealed that the yield attained with low management had significantly higher positive correlation of 0.672* with soil depth, while a significant negative correlation of –0.797** existed with drainage variable across four watersheds. The yield attained under improved management had a significantly higher correlation of -0.814** with drainage, followed by -0.631* with erosion. The mean yields over management levels also showed a similar tend of a significant negative correlation with drainage (-0.845**) and erosion (-0.572*). Among different soil characteristics, a significantly higher negative correlation existed between depth and silt (0-63*); sand and clay (-0.952**); depth and OC (-0.581*); erosion and CEC (-0.571*); sand and CEC (-0.851**), while significantly positive correlation existed between AWC and pH-0.601*); and clay and CEC (0.791**). Significantly positive correlation also observed between sand and BD (0.555*); depth and pH (0.555*) while a negative correlation observed between sand and OC (-0. 540*).

Assessment of effect of soil-site characteristics on soybean yield

Based on linear and quadratic models (Table 3), the effects of erosion, drainage, depth, clay, AWC, OC, $CaCO_3$ and CEC, were assessed and are given in Table 3. It was observed that drainage and depth significantly influenced the soybean yield attained under low management with a predictability of 0.64 and 0.45 under linear model and 0.65 and 0.45 under quadratic equation model for the two characteristics, respectively. In case of improved management, erosion and drainage were found to be important with a significant influence on the yield levels attained across watersheds. There was yield predictability of 0.66** with drainage both under linear and quadratic model while with erosion a higher predictability of 0.51* under quadratic model followed by 0.40* under linear model. In case of mean of low and improved management levels, drainage and OC were found to be significantly influencing yield with a predictability of 0.72** for drainage under both linear and quadratic model compared to 0.31* under linear and 0.38* under quadratic for OC observed across the four watersheds. The study indicated that there was a negative influence of erosion, drainage and OC while positive influence of depth, clay, AWC, $CaCO_3$ and CEC based on the models for low management levels of soybean yield. However, the erosion, drainage, OC and $CaCO_3$ had a negative effect while depth, clay, CEC and AWC had a positive effect on the yield attained with improved management with a similar trend under mean of both levels of management. The prediction error was found to be lowest of 1.063 q ha^{-1} based on drainage, compared to a maximum of 1.724 q ha^{-1} with $CaCO_3$ for yield attained under low management with linear regression model. Compared to this, the prediction error ranged between 1.106 and 1.778 q ha^{-1} for these

Table 1. Soil-site characteristics of the soil units and soybean yield (mean of 2002-03 and 2003-04) under two management levels in four microwatersheds.

Soil Unit	Site characteristics			Soil physical characteristics						Soil chemical characteristics					Soybean yield (q ha^{-1})		
	Slope (%)	Erosion (ratings)	Drainage (ratings)	Depth (m)	Sand (%)	Silt (%)	Clay (%)	BD (Mg m^{-3})	AWC (%)	pH (1:2.5)	EC (ds m^{-2})	OC (%)	$CaCO_3$ (%)	CEC (cmol(p)/kg)	LM	IM	Mean
Varkhed-a	2	2	4	0.30	15.94	30.06	54.00	1.26	9.60	6.51	0.17	0.68	1.50	43.72	7.33	8.13	7.73
Varkhed-b	3	1	3	0.71	3.72	29.19	67.09	1.19	10.26	7.44	0.30	0.61	22.07	56.95	8.14	11.66	9.90
Varkhed-c	2	1	2	1.15	6.96	25.71	67.32	1.12	13.47	7.82	0.28	0.49	12.64	57.35	9.27	13.57	11.42
Jaitpura-a	2	2	3	0.45	28.93	38.10	32.64	1.53	14.55	7.69	0.31	0.20	0.10	45.76	6.14	11.58	8.84
Jaitpura-b	3	2	3	1.68	15.71	26.10	58.19	1.56	7.29	7.68	0.33	0.15	0.10	52.98	8.66	11.03	9.85
Jaitpura-c	3	2	2	1.10	13.32	27.10	59.58	1.15	7.08	7.95	0.24	0.27	0.10	41.13	9.18	12.54	10.86
Panubali-a	5	2	4	0.55	9.81	31.27	58.92	1.40	7.24	6.47	0.10	1.17	0.10	41.89	5.30	5.50	5.15
Panubali-b	3	2	4	1.50	11.52	29.88	58.59	1.45	19.63	8.25	0.33	0.53	10.90	49.22	8.56	9.26	8.91
Panubali-c	3	3	2	1.50	7.40	30.84	68.76	1.63	18.49	8.29	0.12	0.37	12.67	54.27	9.95	10.60	10.27
Khuj-a	3	4	4	1.46	48.40	23.93	27.66	1.60	7.33	7.41	0.37	0.16	5.30	21.94	6.63	7.45	7.04
Khuj-b	1	1	3	1.45	27.50	27.66	44.62	1.68	12.59	7.27	0.15	0.22	1.27	39.85	9.08	16.06	12.56
Khuj-c	3	1	1	1.65	23.21	25.69	51.20	1.47	10.87	7.30	0.34	0.24	1.22	44.78	11.19	19.67	15.43
Min	1	1	1	0.30	3.72	23.93	27.66	1.12	7.08	6.47	0.10	0.15	0.10	21.94	5.30	5.50	5.15
Max	5	4	4	1.68	48.40	38.10	68.76	1.68	19.63	8.29	0.37	1.17	22.07	57.35	11.19	19.67	15.43
Mean	2.8	1.9	2.9	1.13	17.70	28.79	54.05	1.42	11.53	7.51	0.25	0.42	5.66	45.82	8.29	11.42	9.83
SD	1.0	0.9	1.0	0.50	12.57	3.74	13.16	0.20	4.34	0.58	0.09	0.30	7.23	9.72	1.68	3.85	2.67
CV	35.1	47.0	34.2	44.2	71.0	13.0	24.4	13.8	37.7	7.7	37.3	70.0	127.6	21.2	20.3	33.7	27.2

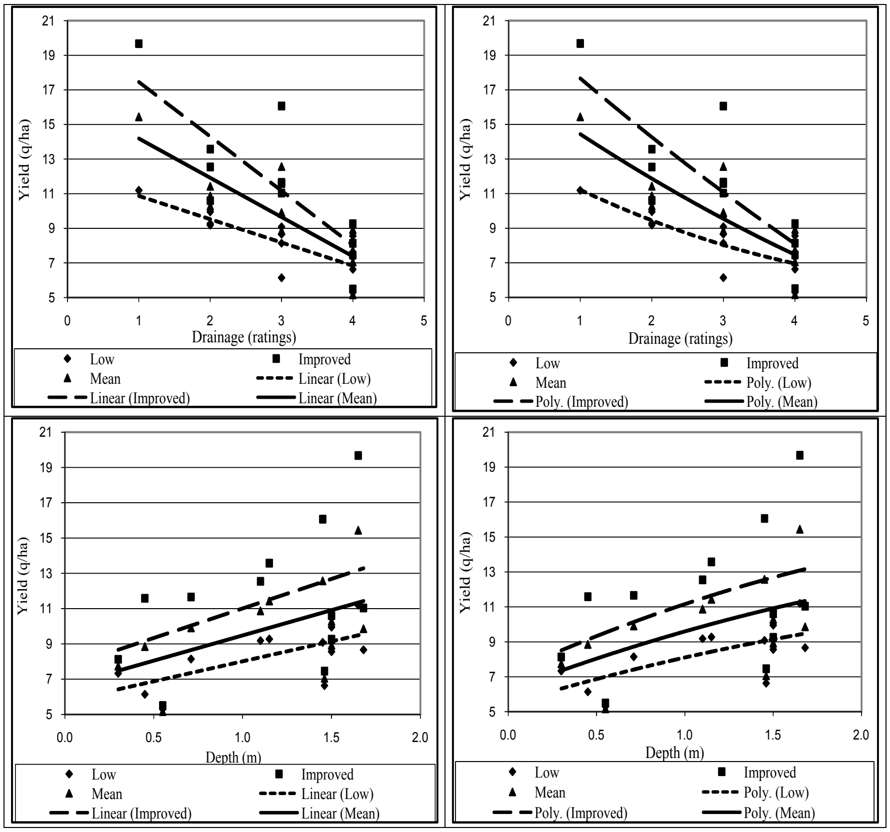

Fig. 1. Relationship between drainage and depth with soybean yield at different management levels

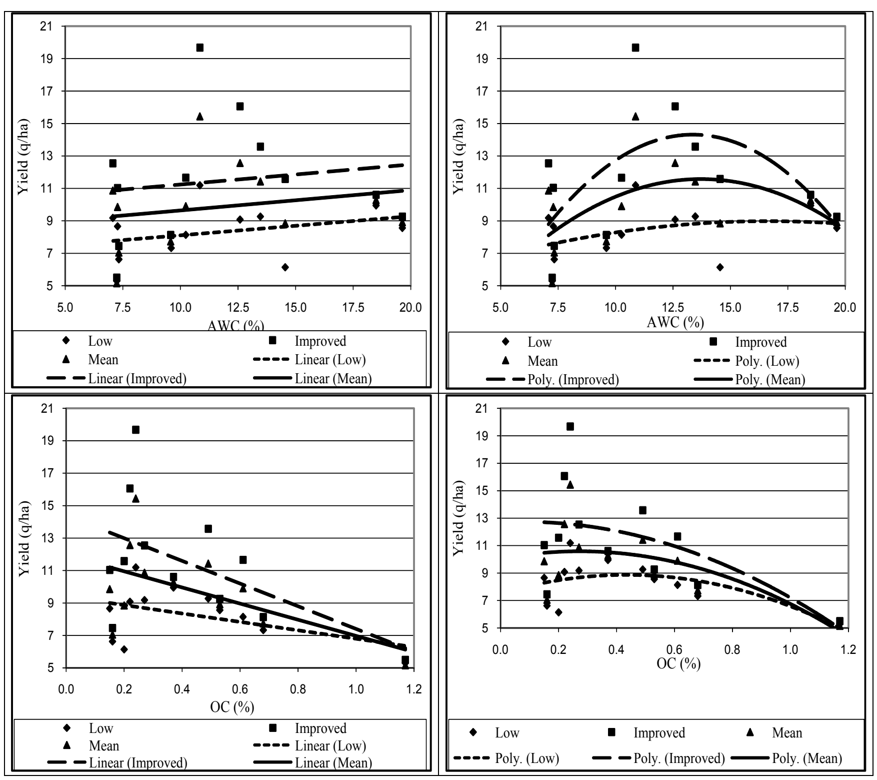

Fig. 2. Relationship between AWC and OC with soybean yield at different management levels

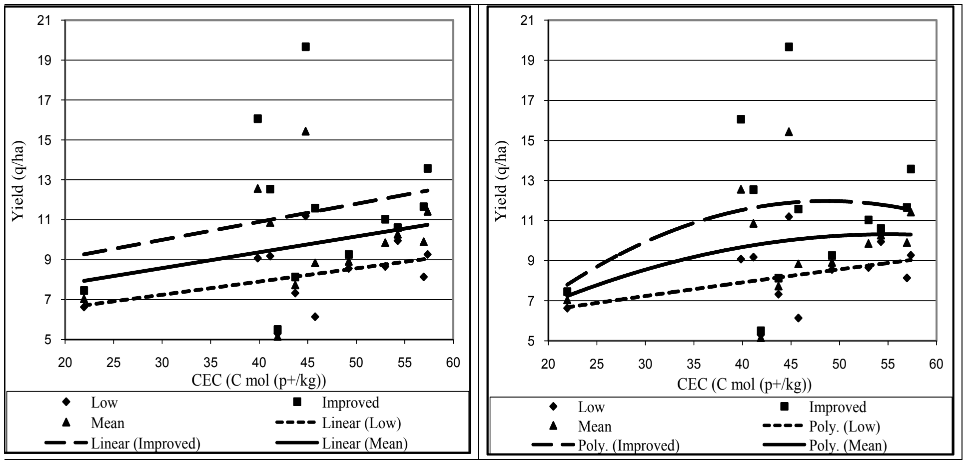

Fig. 3. Relationship between CEC with soybean yield at different management levels

two variables respectively. In case of yield, predictability under improved management, the prediction error ranged between 2.345 q ha^{-1} under linear and 2.469 q ha^{-1} under quadratic regression model for drainage to a maximum of 4.226 q ha^{-1} under quadratic regression model for $CaCO_3$. A similar trend existed for the range of prediction error using the models for mean of management levels.

Among different soil-site characteristics, soil depth showed a maximum negative effect of 2.269 q ha^{-1} for a unit change under low management. A similar trend existed with improved management i.e. a maximum decrease of 6.989 q ha^{-1} in yield for a unit change in OC while a maximum increase of 3.346 q ha^{-1} with a unit change in depth. Among other characteristics, drainage and erosion showed a negative effect of -1.344 and -0.694 q ha^{-1} respectively, while clay, AWC, CEC and $CaCO_3$ increased the yields attained under low management. Similarly, erosion, drainage and $CaCO_3$ reduced the yields, while depth, clay, AWC and CEC increased the yield under improved management across the four watersheds. Similar trends were observed under mean of both management levels in the study.

A graphical plot of yield attained at different ratings of drainage and values of soil depth is given in Fig. 1. Soybean yield decreased with an increased rating of drainage compared to increased yield with an increase in the depth. Moderately well drained condition is found to be optimum for stabilizing soybean yield, since there was reduction in yield with poor and imperfectly drained condition. Soil depth of 100-120 cm was ideal for stable soybean yield, since there was not much increase in the yield when the soils were deeper than this limit.

The effects of AWC and OC are graphically shown in Fig.2 and the effects of CEC on yield under linear and quadratic model are shown in Fig.3. It is observed that there was no significant increase in yield with changes in AWC based on linear model, while there was a significant increase in the yield under improved management based on quadratic model. Thus the quadratic model indicated that the AWC of 12.5% was optimum for attaining yield of about 14 - 15 q ha^{-1} under improved management while it has no influence under low management. Organic Carbon maintained at 0.60% found to be necessary for attaining a stable yield of about 11 q ha^{-1} with improved management compared to about 7 q ha^{-1} under low management. CEC as an index of the native fertility status of the soil, was found to be the one of the most important yield contributing soil characteristic. The increased CEC level was found to be beneficial for attaining higher soybean yield with either improved management or low management. It is observed that a CEC of about 45 cmol (p+) kg^{-1} was ideal for attaining a yield level of 11 q ha^{-1} with improved management compared to about 8 q ha^{-1} with low management as observed in both the regression models, however, it should again be limited up to the genetic yield potential of the crop. Soybean being an exhaustive crop in terms of nutrient up take (Weiss, 1983), the relations with CEC and clay % is obvious.

The above discussion was focused on the independent effects of soil-site characteristics on soybean yield. However, in real sense it may be true, since the soil as a medium is defined by a set of characteristics which together influence the growth and yield of a crop, up on interactions among themselves. Hence, the multiple regression models were calibrated (Table 4) to assess the effects of important soil- site characteristic in the presence of other characteristics *viz,.* drainage, soil depth, AWC, OC and CEC, based on the correlation, linear and quadratic regression analysis, as described in the earlier sections. The models indicated a significant and higher yield predictability of 0.83 for low management compared to a higher and non-significant predictability of 0.71 with improved management. Drainage significantly negatively influenced the yield while soil depth showed significantly positive influence. Drainage is an important site characteristic, which is related to hydraulic conductivity of the swell-shrink and associated soils, particularly with smectitic mineralogy, influences soybean rhizosphere. DeFelice *et al.* (2006) observed that soil drainage is one of the most important factor affecting soybean yields and further, indicated poorly drained soil conditions reduced soybean yields. Soil depth is very critical for rainfed soybean, since the deeper soils with ideal clay % will have solum that has high moisture storage capacity and high CEC and also supports the crop favorably in terms of ideal rhizosphere conditions. Soybean cultivated under rainfed condition is sensitive to soil moisture stress (Shivaramu *et al.,* 1998) and needs assured water availability during growth and development stage. Hence, the soil types that facilitate maximum rainwater storage and support the soybean crop by supplying moisture during dry spells are ideal in realizing good yields In this study, AWC contributed positively under both levels of management. OC and CEC influenced yield positively under low management compared to negatively under improved management. The response to OC and CEC were found to be positive and higher under low management compared to negative and lower under improved management.

The study indicated a positive effect of depth, AWC and negative effect of drainage and OC. Here. The negative effect of OC may be attributed to no further yield realization after certain critical limits or less response of the crop with high OC and high fertilizer application. The multiple regression models indicated that soybean yield could be precisely predicted with a low prediction error of 0.936 q ha^{-1} under low management compared to a high of 2.791 q ha^{-1} under low and improved management levels. Thus, the graphical plots and also the multiple regression models have clearly indicated that rainfed soybean yield can be improved in soils with an increased soil depth, AWC, OC and CEC under low management while with deeper soil and high AWC only under improved management. Soil and crop management strategies should be adopted for improving soil drainage since it severely hampers the yield.

Across the four watersheds in Maharashtra and Madhya Pradesh, for improving the productivity of rainfed soybean cultivated in swell-shrink and associated soils, four soil-site characteristics viz., soil depth, AWC, OC and CEC, with ideal conditions are essential for attaining a yield of 7- 8 q ha^{-1} with low management while only two soil characteristics viz., soil depth and AWC are very important for attaining an yield of 12 – 14 q ha^{-1} with improved management. Besides these soil-site characteristics identified under each management level, drainage is the most important site characteristic that also decides soybean productivity. Since, majority of the soybean growing areas in semiarid tropics in India are characterized with swell-shrink soils, by matching these soil requirements of soybean with the soil-site characteristics of a soybean growing agroecological subregion, it becomes rational in identification of soybean crop suitability for that region and taking ideal crop management decisions for higher productivity.

Table 2. Correlation matrix of soil site characteristics with soybean yield under low and optimum management levels in 4 micro-watersheds

Variable	Erosion	Drainage	Depth	Sand	Silt	Clay	BD	AWC	pH	EC	OC	$CaCO_3$	CEC	LM_Y	OM_Y	Mean_Y
Slope	0.288	0.165	-0.062	-0.255	-0.007	0.263	-0.101	-0.297	-0.178	-0.100	0.572*	0.005	-0.051	-0.305	-0.493	-0.470
Erosion	1	0.397	0.119	0.486	-0.020	-0.400	0.408	-0.058	0.137	0.046	-0.152	-0.115	-0.571*	-0.372	-0.631*	-0.572*
Drainage		1	-0.388	0.212	0.217	-0.311	0.135	-0.114	-0.395	-0.093	0.416	-0.055	-0.373	-0.0797**	-0.814**	-0.845**
Depth			1	0.191	-0.63*	0.036	0.470	0.193	0.557	0.334	-0.581*	0.038	-0.042	0.672*	0.433	0.533
Sand				1	-0.159	-0.952**	0.555	-0.246	-0.147	0.376	-0.540	-0.464	-0.851**	-0.249	0.027	-0.054
Silt					1	-0.112	0.102	0.402	-0.023	-0.287	0.249	-0.070	0.229	-0.468	-0.255	-0.338
Clay						1	-0.510	0.196	0.212	-0.345	0.438	0.512	0.791**	0.423	0.036	0.156
BD							1	0.239	0.099	-0.044	-0.404	-0.307	-0.352	-0.017	0.033	0.018
AWC								1	0.601*	-0.055	-0.080	0.426	0.431	0.304	0.140	0.204
pH									1	0.353	-0.543	0.389	0.343	0.496	0.239	0.343
EC										1	-0.543	0.130	-0.090	0.131	0.233	0.223
OC											1	0.166	0.181	-0.459	-0.540	-0.553
$CaCO_3$												1	0.513	0.204	-0.039	0.043
CEC													1	0.383	0.228	0.288
LM_Y														1	0.784**	0.894**
OM_Y															1	0.979**

* and ** indicate significance at 5 and 1% level

Table 3. Linear and quadratic regression models to predict soybean yield through soil site characteristics under low and optimum management levels in 4 micro-watersheds

Variable	Linear regression model	R^2	Error	Quadratic regression model	R^2	Error
Low management						
Erosion	Y = 9.62 – 0.694 (Erosion)	0.14	1.635	Y = 11.13 – 2.264 (Erosion) + 0.338 $(Erosion)^2$	0.18	1.684
Drainage	Y = 12.21** - 1.344 ** (Drainage)	0.64**	1.063	Y = 13.33** - 2.292 (Drainage) + 0.174 $(Drainage)^2$	0.65**	1.106
Depth	Y = 5.73** + 2.269* (Depth)	0.45*	1.304	Y = 5.44 + 2.417 (Depth) – 0.384 $(Depth)^2$	0.45*	1.372
Clay	Y = 5.37* + 0.054 (Clay)	0.18	1.596	Y = 1.97 + 0.206 (Clay) – 0.002 $(Clay)^2$	0.20	1.659
AWC	Y = 6.93** + 0.117 (AWC)	0.09	1.678	Y = 4.60 + 0.526 (AWC)- 0.016 $(AWC)^2$	0.12	1.745
OC	Y = 9.39** - 2.594 (OC)	0.21	1.565	Y = 7.52** + 6.205 OC) – 7.149 $(OC)^2$	0.39	1.445
CaCO3	Y = 8.02** + 0.047 ($CaCO_3$)	0.04	1.724	Y = 7.82** + 0.186 ($CaCO_3$) – 0.007 (CaCO	0.08	1.778
CEC	Y = 5.25* + 0.066 (CEC)	0.15	1.627	Y = 5.06 + 0.076 (CEC) + 0.001 $(CEC)^2$	0.15	1.714
Improved management						
Erosion	Y = 16.59** - 2.696 (Erosion)	0.40*	3.128	Y = 22.58** - 8.90 (Erosion) + 1.335 $(Erosion)^2$	0.51*	2.964
Drainage	Y = 20.58** - 3.141** (Drainage)	0.66**	2.345	Y = 21.26** - 3.708 (Drainage) + 0.104 $(Drainage)^2$	0.66**	2.469
Depth	Y = 7.66* + 3.346 (Depth)	0.19	3.636	Y = 7.18 + 4.583 (Depth) – 0.614 $(Depth)^2$	0.19	3.831
Clay	Y = 10.86 + 0.010 (Clay)	0.001	4.031	Y = -3.92 + 0.672 (Clay) – 0.007 $(Clay)^2$	0.08	4.075
AWC	Y = 9.99* + 0.124 (AWC)	0.02	3.994	Y = -10.66 + 3.737 *(AWC) – 0.140 * $(AWC)^2$	0.37	3.368
OC	Y = 14.39** - 6.989 (OC)	0.29	3.396	Y = 12.68 + 1.024 (OC) - 6.511 (OC)2	0.32	3.506
CaCO3	Y = 11.54** - 0.021 ($CaCO_3$)	0.002	4.030	Y = 11.77** - 0.183 ($CaCO_3$)+ 0.009 $(CaCO_3)^2$	0.012	4.226
CEC	Y = 7.29 + 0.09 (CEC)	0.05	3.927	Y = -1.85 + 0.568 (CEC) – 0.006 $(CEC)^2$	0.09	4.056
Mean of low and improved management						
Erosion	Y = 13.08** - 1.697 * (Erosion)	0.33	2.299	Y = 16.92** - 5.674 (Erosion) + 0.856 $(Erosion)^2$	0.43	2.239
Drainage	Y = 16.44** - 2.267** (Drainage)	0.72**	1.497	Y = 17.24** - 2.940 (Drainage) + 0.124 $(Drainage)^2$	0.72**	1.573
Depth	Y = 6.61** + 2.865 (Depth)	0.29	2.370	Y = 6.24 + 3.813 (Depth) – 0.470 $(Depth)^2$	0.29	2.497
Clay	Y = 8.11* + 0.032 (Clay)	0.02	2.768	Y = -0.83 + 0.432 (Clay) – 0.004 $(Clay)^2$	0.09	2.825
AWC	Y = 8.39** - 1.697 * (AWC)	0.04	2.744	Y = -3.24 + 2.160 (AWC)- 0.079 $(AWC)^2$	0.27	2.518
OC	Y = 11.94** - 4.978 * (OC)	0.31*	2.335	Y = 10.04** + 3.960 * (OC) – 7.26	0.38	2.324
CaCO3	Y = 9.74** + 0.016 ($CaCO_3$)	0.002	2.799	Y = 9.75** + 0.009 ($CaCO_3$) + 0.001 $(CaCO_3)^2$	0.002	2.951
CEC	Y = 6.200** + 0.079 (CEC)	0.08	2.683	Y = 1.80 + 0.309 (CEC) – 0.003 $(CEC)^2$	0.10	2.800

* and ** indicate significance at 5 and 1% level

Table 4. Multiple regression models of soybean yield through soil site characteristics under low and optimum management levels in 4 micro-watersheds.

Management	Multiple regression model	R^2	Error
Low	Y = 7.69* - 0.949* (Drainage) + 1.536* (Depth) + 0.034 (AWC) + 0.113 (OC) + 0.026 (CEC)	0.83*	0.936
Improved	Y = 20.41* – 2.755* (Drainage) + 0.113 (Depth) + 0.039 (AWC) – 2.949 (OC) – 0.006 (CEC)	0.71	2.791
Mean	Y = 13.99** – 1.842* (Drainage) + 0.809 (Depth) + 0.038 (AWC) – 1.644 (OC) + 0.012 (CEC)	0.79*	1.667

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