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Soil-Site Suitability Evaluation for Pearl Millet in the Soils of North-West Gir Madhuvanti Toposequence of South Saurashtra Region of Gujarat

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Abstract Six representative pedons were evaluated for their soil site suitability of pearl millet [*Pennisetum glaucum* [L.)] in the soils of different land slopes of North-West Gir Madhuvanti toposequence of south Saurashtra region of Gujarat. The soils of lower piedmont belong to Vertic Haplusterts (P_3) were highly suitable (S_1) for pearl millet. The soils of upper piedmont belong to Lithic Ustorthents (P_2), plain area belong to Typic Haplusterts (P_4) and depression area belong to Sodic Haplusterts (P_5) were moderately suitable (S_2) for pearl millet, whereas the soils of upper coast belong to Fluventic Calciustepts (P_6) were marginally suitable (S_3) and hill slopes belong to Lithic Ustorthents (P_1) were currently not suitable (N_1) for pearl millet. Topography, drainage, shallow soil depth, high $CaCO_3$, soil salinity and poor soil fertility (low O. C.) are the major limitations in majority of soils of North-West Gir Madhuvanti toposequence of south Saurashtra.

Keywords Soil-site suitability, Land slopes, Pearl millet, North-West Gir Madhuvanti toposequence, Toposequence.

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Introduction

The demands on the finite land resources are increasing exponentially due to the growing population at the rate of 1.67% for meeting the needs of food, fodder, fuel, fiber and other raw materials. It has been estimated that India's population may reach 1.5 billion by about 2035 AD. The per capita cultivable land was 0.5 ha in 1951-52, which declined to 0.14 ha by 2000. AD and may further come down to 0.09 ha by 2020 [1]. The food production, no doubt increased from 52 MT (in 1950's) to almost 270 MT (in 2016-2017), but this has been largely as a result of expansion in cultivated area and high input. This significant growth of agriculture has been at a cost decline in soil quality and risk of soil degradation. This may further deteriorate with a risk of jeopardizing country's food security. This demands our focused attention to develop alternative land use options and identifying best possible area for a given crop for sustaining and optimizing the production. It necessitates the appropriate interpretation of soil data base in terms of their suitability for different agricultural/non-agricultural uses to rationalize land use.

Pearl millet [*Pennisetum glaucum* (L.)] is the fifth most important cereal crop in the world after rice, wheat, maize and sorghum. It is a widely grown cereal crop in the arid and semi-arid areas in the world for both food and forage production. Its grain is more nutritious and the protein content is not only high

Table 1. Climate and soil-site suitability criteria for pearl millet.

Land characteristics	S_1	S_2	S_3	N_1	N_2
Climatic (c)					
Precipitation (mm)	400–600	300–400	200–300	< 200	–
Mean temp (°C)	20–28	18–20	16–18	< 16	–
Topography (t)					
Slope (%)	< 1–3	3–8	8–15	> 15	–
Wetness					
Drainage	Well	Mod	Imp	Poor	Poor
Physical characteristics (s)					
Texture / structure	c, cl, fl	cl-s, scl	sl, lfs, cl-s	fs-s	cs, s
Coarse fragments (%)	< 15	15–35	35–55	> 55	–
Soil depth (cm)	> 50	25–50	< 25	–	–
$CaCO_3$ (%)	0–25	25–50	< 25	–	–
Gypsum (%)	0–6	6–10	10–20	> 20	–
Soil fertility characteristics (f)					
CEC cmol (p^+) kg^{-1}	> 5	3–5	2–3	< 2	–
BS (%)	> 50	50–35	< 35	–	–
Organic carbon (%)	0.4	0.2–0.4	< 0.2	–	–
Salinity alkalinity (n)					
ECe (dsm^{-1})	< 4	4–8	8–12	> 12	–
ESP (%)	< 25	25–35	35–45	> 45	–

but it is also of good quality. The grain contains 11–19% protein, 60–78% carbohydrates and 3.0–4.6% fat and also has good amount of phosphorus and iron. It has the maximum potential of all the millets and is mainly grown in drought prone areas and marginal soils, India is the largest producer of pearl millet, both in terms of area (9.3 m ha) and production (9.3 MT), with an average productivity of 1044 kg ha^{-1} during the last five years [2].

Yield of any crop is influenced by kind of soils occurring in the area, prevailing climate, topography and management levels. Thus, it is essential to interpret the soil site, characteristics of any place in terms of their suitability for crops grown in the area and alternative land use planning. The crop management practices based soil and site suitability criteria may help to overcome the constraints of crop planning for maximizing the production. It also helps in appraisal of suitability of a particular crop in specific soil/area. Land suitability evaluation is the process of estimating the potential of land for land use planning. Several workers have worked out the suitability of soils for various crops such as sorghum [3]. The soils of Saurashtra region are unique in origin having diverse genesis, physiography, climate, vegetation, depth, color and age. An understanding of soil characteristics are helpful in the pedogenic that may have taken place during the developmental process and in planning the appropriate management practices for its efficient land utilization planning. In order to develop some understanding on the nature of the and /or the potential for agriculture production such evaluation will help in the future planning for optimum use of natural resources. In order to suggest suitable management practices and remedial measures to tackle soil constraints, both field and laboratory studies of soils of the area are essential. Keeping view, the present study was undertaken to evaluate soil-site suitability of pearl millet.

Materials and Methods

The study area (North-West Gir Madhuvanti

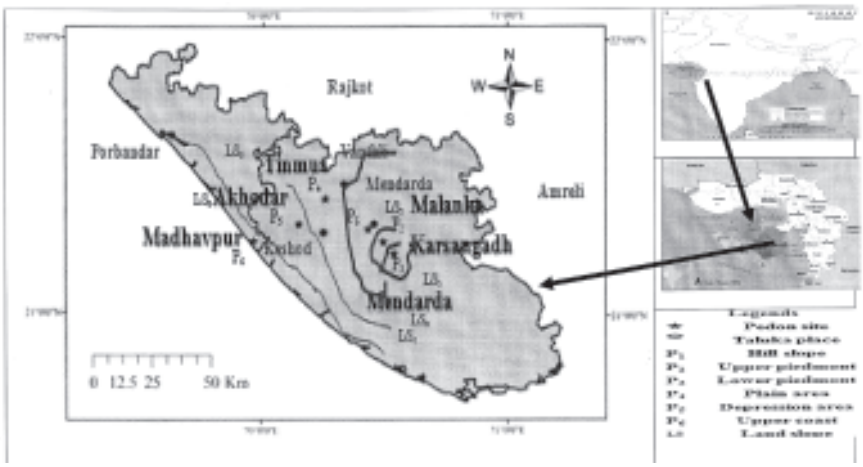

Fig. 1. Site of pedons of North-West Gir Madhuvanti toposequence in South Saurashtra.

toposequence) was located between 21°13´ to 21° 25´N latitudes and 69°57´ to 70°32´E longitudes encompassing parts of the Mendarda, Vanthli and Keshod tehsils of Junagadh district and Porbandar tehsil of Porbandar district of South Saurashtra at an elevation ranged from 5 to 190 above mean sea level. IRS IA LISS II FCC imagery on 1 : 50,000 scale in conjunction with Survey of India topographical (SOI) map referred above on 1 : 50,000 scale were used to select various land slopes of North-West Gir Madhuvanti toposequence of South Saurashtra region of Gujarat namely: hill slope (LS-1), upper piedmont (LS-2), lower piedmont (LS-3), plain area (LS-4),depression area (LS-S) and upper coast (LS-6) (Fig. 1). The mean annual rainfall is 1120 mm and the climate of the area is semi-arid characterized by extremes of temperature and low wind velocity. Horizon-wise soil samples collected from the typifying pedons were analyzed for their physical and chemical characteristics following standard procedure and soils were classified according to Key to Soil Taxonomy [4]. The soil-site suitability for pearl millet was carried out using limitation method and matched with generated data (Table 1) at different limitation level : S_1–highly suitable, S_2–moderately suitable, S_3–marginally suitable, N_1–currently not suitable and N_2– not suitable. The soil site suitability and land quality criteria of studied soil are given in Table 2.

Table 2. Soil characteristics of North-West Gir Madhuvanti toposequence of South Saurashtra (weighted mean).

Pedon	Particle size (%) Sand	Silt	Clay	pH (1:2.5)	ECe (dSm^{-1})	Org C (%)	$CaCO_3$ (%)	CEC [cmol (P^+) kg^{-1}]	BS (%)	ESP
P_1	34.81	36.29	28.90	6.79	0.28	0.84	2.75	20.60	88.44	0.53
P_2	22.94	43.65	33.40	7.90	0.35	0.68	31.80	25.78	91.36	2.56
P_3	14.26	29.50	56.23	8.04	0.91	0.60	19.81	30.83	92.03	5.80
P_4	24.22	37.13	38.65	8.13	1.66	0.50	19.98	34.66	94.04	10.80
P_5	19.67	40.25	40.07	8.20	2.17	0.49	20.05	42.94	94.10	13.03
P_6	21.07	46.61	32.31	8.28	3.08	0.37	25.20	43.96	96.31	16.93
Over-all mean	22.83	38.90	38.26	7.89	1.41	0.58	19.93	33.18	92.71	8.27

Table 3. Soil-site suitability evaluation and land qualities for the pearl millet of the soils of North-West Gir Madhuvanti toposeqence of South Saurashtra. C–Clay, Sicl–Silty clay loam, L–Loam, CL–Clay loam.

	Climate (c)		Wetness (w)		Physical & chemical characteristics (s)		
Pedon No.	Rainfall (mm)	Temp (°C)	Topo-graphy (slope %)	Drainage	Texture	Soil depth (cm)	$CaCO_3$ (%)
P_1	1120	27.31	15–30	Somewhat excessive	L	25	2.75
P_2	1120	27.31	3–8	Well	Cl	27	31.80
P_3	1120	27.31	1–3	Well	C	70	19.81
P_4	1120	27.31	0–1	Well	C	94	19.98
P_5	1120	27.31	0–1	Moderately Well	C	105	21.05
P_6	1120	27.31	0–1	Imperfect	Sicl	127	25.20

Table 3. Continued.

	Soil fertility characteristics (f)				Salinity / Alkalinity (n)	
Pedon No.	OC (%)	BSP	CEC (cmol (p^+) kg^{-1})	pH	EC (dSm^{-1})	ESP
P_1	0.84	88.44	20.60	6.79	0.63	0.53
P_2	0.68	91.36	25.78	7.90	0.88	2.56
P_3	0.60	92.03	30.83	8.04	2.86	5.80
P_4	0.50	94.04	34.66	8.13	5.95	10.80
P_5	0.49	94.10	42.94	8.20	7.86	13.03
P_6	0.37	96.31	43.96	8.28	11.82	16.93

Results and Discussion

The soils of different pedons of North-West Gir Madhuvanti toposequence of South Saurashtra region have the total sand, silt and clay content with overall mean values of 22.83, 38.90 and 38.26%, respectively (Table 2) indicating dominant of loam to clayay texture. The soil pH, organic carbon and $CaCO_3$ ranged from 6.79 to 8.28, 0.37 to 0.84% and 2.75 to 31.80% with the overall mean value of 7.89, 0.58% and 19.93%, respectively. The medium organic carbon content in the soils might be attributed to the prevalence of tropical condition, where the degradation of organic matter occurs at faster rate with low vegetation cover, thereby leaving less organic carbon in the soils [5—7]. The pH of the soils of North-West Gir Madhuvanti toposequence was observed to follow an increasing sequence Hill slope < Upper piedmont < Lower piedmont < < Plain area < Depression area < Upper coast. A through examination of the data revealed that an increase in soil pH gradually along the topography from hill slope to upper coast could be the result of contonuous flow of bases from higher topography to lower topography of North-West Gir Madhuvanti toposequence. This finding is in conformity with that of Savalia [5]. The $CaCO_3$ content was found in the increasing order of Hill slope < Lower piedmont < Plain area < Depression area < Upper coast < Upper piedmont.

The content of $CaCO_3$ in general increased down the slope and it registered its maximum value in upper piedmont (31.80%) because the upper piedmont area has a rich source of lime stone. The ECe ranged from 0.63 to 11.82 dSm^{-1} (weighted mean of 5.00 dSm^{-1}) indicating that the soils of different pedons of North-West Gir Madhuvanti toposequence were in general moderately saline in nature. The ECe, in different pedons were in the order of Hill slope < Upper piedmont < Lower piedmont < Plain area < Depression area < Upper coast, indicating the ECe increased with decreasing topography. Similar results were also

Table 4. Soil-site suitability evaluations for pearl millet crops in the soils of North-West Gir Madhuvanti toposequence of South Saurashtra. S_1 = Highly suitable, S_2 = Moderately suitable, S_3 = Marginally suitable, N_1 = Currently not suitable.

	Climate (c)		Wetness (w)		Physical & chemical characteristics (s)			Soil fertility characteristics (f)			Salinity/ Alkalinity (n)		
Pedon No.	Rainfall (mm)	Temp (°C)	Topography (slope %)	drainage	Texture	Soil depth (cm)	$CaCO_3$ (%)	OC (%)	BSP	CEC (cmol (p^+) kg^{-1})	ECe (dSm^{-1})	ESP	Crop suitability class
P_1	S_1	S_1	N_1	S_3	S_1	S_2	S_1	S_1	S_1	S_1	S_1	S_1	N_1ws
P_2	S_1	S_1	S_2	S_1	S_1	S_2	S_2	S_1	S_1	S_1	S_1	S_1	S_2 ws
P_3	S_1	S_1	S_1	S_1	S_1	S_1	S_1	S_1	S_1	S_1	S_1	S_1	S_1
P_4	S_1	S_1	S_1	S_1	S_1	S_1	S_1	S_1	S_1	S_1	S_2	S_1	S_2 n
P_5	S_1	S_1	S_1	S_2	S_1	S_1	S_1	S_1	S_1	S_1	S_2	S_1	S_2 wn
P_6	S_1	S_1	S_1	S_3	S_1	S_1	S_2	S_2	S_1	S_1	S_3	S_1	S_3 wsfn

reported earlier [5, 7, 8] along the transact. The cation exchange capacity in the studied soils ranged from 20.60 and 43.96 cmol (P^+) kg^{-1} with the mean value of 33.18 cmol (P^+) kg^{-1}. The CEC recorded in the increasing order of Hill slope < Upper piedmont < Lower piedmont < Plain area < Depression area < Upper coast indicating that CEC increased with decreasing topography. The BSP and ESP ranged from 88.73 to 96.31 and 0.51 to 16.93 with the mean value of 92.71 and 8.27, respectively (Table 2) indicating mode of sodicity. The content of BSP and ESP were found in increasing sequence of Hill slope < Upper piedmont < Lower piedmont < Plain area < Depression area < Upper coast (Table 2) indicating BSP and ESP increases with decreasing an elevation. The results are in concurrence with those obtained earlier [5, 7, 8]. In general, the soils of North-West Gir Madhuvanti toposequence were moderately alkaline in reaction, low inorganic carbon and highly calcareous in nature. The soil at higher elevation have low in pH, EC, CEC, BSP and ESP then lower elevation.

Soil-site suitability for different land uses is very important for alternate and suitable land use planning. The soil site evaluation and land use criteria of different land slope are given in Table 3 and Table 4.

Table 5. Limitation levels of the land characteristics and land suitability class for pearl millet. S_1 = Highly suitable, S_2 = Moderately suitable, S_3 = Marginally suitable, N_1 = Currently not suitable, W = Wetness, S = Physical characteristics, F = Soil fertility characteristics, N = Salinity / Alkalinity hazard.

No. of Pedon	Sub group	Soil-site suitability class for pearl millet
Pedon–1	Hill slope (Karsangadh), MSL : 190 m, 21°13′ N latitudes, 70°32′ E longitude, Lithic Ustorthent	N_1 ws
Pedon–2	Upper piedmont (Malanka), MSL : 155 m, 21°16′ N latitudes, 70°29′E longitude, Lithic Ustorther	S_2 ws
Pedon–3	Lower piedmont (Mendarda), MSL : 92 m, 21°18′ N latitudes, 70°25′ E longitude, Vertic Hapluste	S_1
Pedon–4	Plain area (Tinmus), MSL : 27 m, 21°25′ N latitudes, 70°15′ E longitude, Typic Haplusterts	S_2 n
Pedon–5	Depression area (Akhodar), MSL : 13 m, 21°19′ N latitudes, 70°08′ E longitude, Sodic Hapluster	S_2 wn
Pedon–6	Upper coast (Madhavpur), MSL : 5 m, 21°16′ N latitudes, 69°57′ E longitude, Fluventic Calciuster	S_3 wsfn

The soil-site suitability evaluation for pearl millet based on comparison of land qualities and crop requirements is given in Table 5.

Pedon-1(Karsangadh) from the hill slope : The soils associated with this pedon were currently not suitable (N_1) for pearl millet cultivation because of major limitations like topography, somewhat excessive drainage and shallow soil depth. Soil conservation measures like graded narrow base terrace bunds or trenches and contour bunding should be adopted [9].

Pedon-2 (Malanka) from the upper piedmont : The soils associated with pedon P_2 have been found to be moderately suitable (S_2) for pearl millet on account of limitations like topography and shallow soil depth for pearl millet. Graded narrow base terrace bunds or trenches are recommended to increase soil depth / rooting volume, conservation tillage and forage-based crop rotations which reduce erosion and allow soil forming factors to maintain and rehabilitate top soil. Similar results were obtained earlier [7, 9, 10].

Pedon-3 (Mendarda) from the lower piedmont : The soils associated with pedon P_3 have been found to be highly suitable (S_1) for pearl millet having no limitation. Similar observations were made earlier [5, 8].

Pedon-4 (Tinmus) from the plain area : The soils associated with pedon P_4 have moderately suitable (S_2) for pearl millet with limitation of soil salinity. On adoption of corrective measures of mulching, rain water leeching and use of organic manures, the suitability class of pearl millet could be corrected. Similar observations were also made by Savalia [5, 7, 8].

Pedon-5 (Akhodar) from the depression area : The soils associated with pedon P_5 have been found to be moderately suitable (S_2) for pearl millet on account of limitations like drainage and soil salinity (Table 5). On adoption of corrective measures like provision of surface drainage through lateral ditch adoption of salt tolerant varieties, mulching, use of organic manures and soil and water conservation practices could be adopted these soils to make them productive. Similar observations were made earlier [5, 7, 8].

Pedon-6 (Madhavpur) from the upper coast : The soils associated with pedon P_6 have been evaluated to be marginally suitable (S_3) for pearl millet on account of limitations like drainage, high $CaCO_3$, poor soil fertility (low O. C.) and soil salinity. On adoption of corrective measures like provision of surface drainage through lateral ditch (Giri et al., 1999), adoption of salt tolerant varieties, use of organic manures along with gypsum and nitrogenous fertilizers and soil and water conservation practices could be adopted in these soils to make them productive. Similar observations were done earlier [5, 7, 8].

Conclusion

Bested on the present study it can be concluded that the soils of study area were moderately alkaline in reaction and highly calcareous in nature. The soils over lower piedmont belong to Vertic Haplusterts (P_3) were highly suitable (S_1) for pearl millet cultivation. The soils of upper piedmont belong to Lithic Ustorthents (P_2), plain area belong to Typic Haplusterts (P_4) and depression area belong to Sodic Haplusterts (P_5) were moderately suitable (S_2) for pearl millet cultivation, whereas upper coast belong to Fluventic Calciustepts (P_6) were marginally suitable (S_3) and hill slopes belong to Lithic Ustorthents (P_1) were currently not suitable (N_1) for pearl millet.

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