RESEARCH PAPER

Soil Characterization, Classification and Suitability Evaluation for Pigeon Pea growing on some Vertisols of Marathwada Region, Maharashtra, India.

*[1]K. R. Malode, [2] Mistry D.Y., [3] Solanki Pravina P. and [4] Suthar Dhara

[1]*Associate Professor, Department of Soil Science and Agricultural Chemistry, COA, Parul University, Vadodara Gujarat, India*
[2.] *Assistant Professor, Department of Agricultural Engineering, PIT, Parul University, Vadodara Gujarat, India*
[3]*Assistant Professor, Department of Horticulture, College of agriculture, Parul University, Vadodara Gujarat, India*
[4]*Assistant Professor, Department of Horticulture, College of agriculture, Parul University, Vadodara Gujarat, India*
[1]*kailash.malode91066@paruluniversity.ac.in,* [2]*dixitKumar.mistry17504@paruluniversity.ac.in,*
[3]*pravinaben.solanki38824@paruluniversity.ac.in and* [4]*dhara.suthar41928@paruluniversity.ac.in*
[1]*ORCID ID: 0000-0002-8963-4709,* [2]*ORCID ID: 0000-0001-5468-1401,* [3]*ORCID ID- 0009-0008-2354-3071 and*
[4]*ORCID ID: 0009-0004-7581-7338*
**Corresponding author: (munna.acss@gmail.com)*

Received: 26th Feb 2026; Revised: 8th March 2026; Accepted: 7th April, 2026; Available Online: 20th April, 2026

ABSTRACT

The soils of Marathwada region of Maharashtra were characterized and evaluated for their suitability for pigeon pea cultivation. The soils varied from shallow to very deep and exhibited grey (10YR 3/1) to dark brown (10YR 5/1) colour. Soil structure ranged from granular to sub-angular blocky, while texture varied from clay loam to clay. The bulk density of soils ranged from 1.27 to 1.56 Mg m^{-3}, whereas saturated hydraulic conductivity varied from 0.4 to 5.3 cm hr^{-1} and generally increased with soil depth. The soils were slightly to moderately alkaline in reaction. The sand, silt and clay contents ranged from 9.7 to 25.9, 19.7 to 31.8 and 51.1 to 62.1 per cent, respectively, in different soil horizons. The cation exchange capacity (CEC) ranged from 40.3 to 62.5 cmol (p^+) kg^{-1}. Majority soils are belong to clayly in nature, Higher soil organic carbon and total carbon contents were generally observed in the surface and sub-surface layers compared with deeper horizons. The available nitrogen, phosphorus and potassium contents ranged from 51.2 to 334.8, 1.0 to 27.10 and 229.6 to 583.8 kg ha^{-1}, respectively, in different pedons. Micronutrient analysis indicated that DTPA-extractable zinc was deficient in most of the soils. Based on field morphology and laboratory characterization, the soils were classified from Lithic Ustorthents to Typic Haplusterts according to USDA Soil Taxonomy. Soil-site suitability evaluation revealed that Pedon P1 was not suitable (N2) for pigeon pea cultivation due to severe limitations such as shallow soil depth and low organic carbon content. In contrast, other soils were found to be moderately suitable to highly suitable for pigeon pea cultivation. The yield-based suitability evaluation indicated that Typic Haplusterts (Pedon P6) belonging to the order Vertisols were highly suitable (S1) and recorded higher productivity compared to other soils of the region. The study highlights the importance of soil depth, organic carbon and moisture retention capacity in determining the suitability of soils for pigeon pea cultivation in the semi-arid agro-ecological zones of the Marathwada region.

Keywords: *Soil organic carbon, soil site characteristics, pigeon pea crop, classification, soil orders*
How to cite this article: Malode KR, Mistry DY, Pravina P S, Dhara S. Soil Characterization, Classification and Suitability Evaluation for Pigeon Pea growing on some Vertisols of Marathwada Region, Maharashtra, India. Int J Drug Deliv Technol. 2026;16(34s):320-329. DOI: 10.25258/ijddt.16.34s.40
Source of support: Nil.
Conflict of interest: None

INTRODUCTION

Pigeon pea (Cajanus cajan L. Millsp.) is one of the most important grain legumes cultivated in tropical and subtropical regions of the world. In India it is popularly known as arhar or tur and constitutes a major component of the diet, particularly for vegetarian populations. The crop belongs to the family Leguminosae and subfamily Papilionaceae, with a chromosome number of 2n = 22. Pigeon pea grains are nutritionally rich, containing approximately 20–25% protein, along with significant amounts of carbohydrates, dietary fiber, vitamins, and essential minerals such as potassium, magnesium, and iron. Owing to its high nutritional value and multiple uses, the crop is often regarded as a valuable component of sustainable dryland agriculture (Upadhyaya, et al., 2012).

In India, pigeon pea is widely cultivated across semi-arid and rainfed regions where it plays an important role in food security, soil fertility improvement, and livelihood support for small and marginal farmers. The crop contributes significantly to soil health through biological nitrogen fixation and the addition of organic residues to the soil system. In the Marathwada region of Maharashtra, pigeon pea forms an integral part of traditional cropping

**Author for Correspondence: munna.acss@gmail.com*

systems due to its drought tolerance, deep rooting habit, and adaptability to limited rainfall conditions. Despite these advantages, the productivity of pigeon pea in this region remains relatively low and unstable, mainly due to erratic rainfall patterns, soil fertility constraints, and sub-optimal land use practices. Recent research efforts, including the development of hybrid pigeon pea varieties by Vasantrao Naik Marathwada Agricultural University, aim to enhance productivity and yield stability under the prevailing agro-climatic conditions (Garud et al., 2021; Malode and Patil, 2014).

The Marathwada region, located on the Deccan Plateau of central Maharashtra, is characterized by a hot semi-arid climate with highly variable monsoon rainfall, high evapotranspiration rates, and frequent dry spells. These climatic conditions impose considerable limitations on crop production, particularly under rainfed farming systems. The growth stages of pigeon pea such as seedling establishment, flowering, and pod filling often coincide with periods of soil moisture stress, which can adversely affect crop yield and stability. Therefore, understanding the interaction between soil characteristics, climate, and crop requirements is essential for improving crop productivity and ensuring sustainable land use in the region.

Soils of Marathwada are predominantly medium to deep black soils (Vertisols) formed from basaltic parent material. These soils are generally characterized by high clay content, considerable water-holding capacity, and pronounced shrink–swell behavior. However, they also exhibit several limitations such as surface cracking, restricted infiltration during certain periods, and relatively low levels of available nitrogen and organic carbon under continuous cultivation. Variability in soil depth, texture, nutrient status, and organic matter content across the landscape significantly influences root growth, moisture availability, and nutrient uptake, which are critical factors determining crop suitability and productivity.

Land suitability evaluation provides a scientific framework for assessing the potential of land resources for specific crops by comparing the biophysical characteristics of soils and climate with the ecological requirements of the crop. Important parameters considered in such evaluations include soil depth, texture, slope, drainage, organic carbon content, nutrient availability, and rainfall patterns. Several studies conducted in dryland agro-ecosystems have demonstrated that appropriate land configuration, soil and water conservation practices, and improved crop management strategies can substantially enhance pigeon pea productivity and soil health (Ramamurthy et al., 2019; Shaloo et al., 2022; Kadu et al., 2003).

Integration of Soil Resource Inventory (SRI) with agro-ecological parameters enables systematic classification of land into different suitability categories such as highly suitable, moderately suitable, marginally suitable, and unsuitable for crop cultivation. Such classification provides valuable information for developing location-specific land management strategies, improving soil and water conservation practices, and optimizing crop production systems. This approach is particularly important in regions like Marathwada, where agricultural productivity is highly influenced by spatial variability in soil and climatic conditions.

The drought-prone and assured rainfall zones of Agro-Ecological Zone-6 in the Marathwada region represent semi-arid ecosystems predominantly dominated by rainfed agriculture and irregular rainfall distribution. These environmental constraints often result in low and unstable crop productivity, highlighting the need for systematic evaluation of land resources. In this context, the present study was undertaken to characterize soils and evaluate land suitability for pigeon pea cultivation across different agro-ecological zones of the Marathwada region. The study integrates detailed analysis of soil physical and chemical properties with GPS-based spatial mapping to support scientific land resource planning and promote sustainable pigeon pea production in the region.

MATERIALS AND METHODS

Geographically, the Marathwada region is located between 74°- 40 to 70 -15’ E longitudes and 17°- 35 to 20°- 40’ N latitudes. The general elevation of the area ranges from 347 to 638 m above mean sea level (MSL). The climate of the study area is arid and semi aridwith well expressed summer (March to May), rainy season (June to October) and winter (November to February). The mean annual temperature is 33-5 °C and means annual precipitation is about 903 mm of which nearly 90 per cent is received during monsoon. The relative humidity is high during monsoon period (75 to 88%) and low during other period (30 to 40%). The area qualifies for *Ustic* and *'Hyperthermic'* respectively.

The natural vegetation compared of major crops growing in the region are soybean (*Glycin max*), cotton (*Gossipiumspp*), pigeonpea (*Cajanuscajan*) and sorghum (*Sorghum biocolor*) in khrif and wheat (*Triticumstivum*) and gram (C*icerarictinum*) in rabi under irrigation or stored moisture pigeon pea crop were growing all districts of Marathwada region of Maharashtra. The land forms, slop and land use/land cover maps were integrated to prepare the physiographic unit map. The profile were exposed in each physiographic unit and studied for morphological properties (Soil survey Division staff, 2000) and classified as per soil Taxonomy (soil survey staff, 1998). Soil map was prepared based on thematic physiographic-soil relationship. The soils were grouped under different productivity classes (Riqier *et.al.*1970). Soil site suitability for pigeon pea was worked out as per the methodology given in the FAO frame work on land evaluation (FAO 1976) as modified by Sys *et al.* (1991). The soil site requirement as suggested by NBSS & LUP (1994) has been use for evaluating the suitability of different mapping unit for pigeon pea crop.

The study area was chosen at Nanded is Moderated rainfall zone, Beed and, Osmanabad, Distics Drought prone zone and Latur and Jalna Districts is Assured rainfall zone of Marathwada region of Maharashtra state. The geology at the area is essentially basalts of the Deccan trap (Waikar S. L. *et al.,* 2003 and Malode and Patil 2014). Six soil sites on different macro topographic conditions were selected and nomenclature the soils of the study area as, P1 were Lithic Ustorthents and P2, P3, P4 and P5 are Typic Haplusterts. The profiles were exposed and examined on each selected site. The morphological characteristics such as structure, texture, consistence, pores, roots, nodules, effervescence, coarse fragment and other feature like deep cracks were observed as seasonal dry and wet periods produced short-term cycles of soil surface crack area density (crack density). In addition, the site characteristics such as location, slope, and climate were also studied. The collected soil samples were air dried, processed and passed through 2 mm sieve for laboratory analysis. Soil properties like particle size distribution were determined as per the international pipette method. Bulk density was determined by dry clod waxing technique, hydraulic conductivity was determined by constant head method. The pH and EC were measured in 1:2.5 soil-water suspension, the each profile soil samples and 30 surface soil sample analyzed for available nitrogen by permanganate method (Subbiah and Asija,1956), available phosphorus by (Chopra and Kanwar, 1976) and available potassium by ammonium acetate extractant (Jakson,1973). Cation exchange capacity (CEC) was determined by 1 NaOAc at pH 8.2. Exchangeable Ca^{2+} was determined by KCI-triethanolamine method followed by EDTA titration, organic carbon was determined by Walkley and Black method (1956) and total carbon was determined by sum of soil inorganic carbon and organic carbon (Technical manual U.S.E.P.A, 2001). Calcium carbonate equivalent was determined by acid neutralization method of Black *et al.* (1965). Available zinc, copper, iron and manganese were extracted by 0.005 M DTPA solution (Lindsay and Norvell, 1978) and analyzed with the help of Atomic absorption spectrophotometer. The soils were classified as par soil Taxonomy (Anonymous, 1994 b), soil-site suitability were made as par the criteria suggested by sys *et al.,* (1991) and modified by NBSS & LUP (Anonymous, 1994a). In addition, suitability classes were also derived based on the actual yield as suggested by FAO (Anonymous, 1983).

RESULTS AND DISCUSSION

Soil site characteristic /soil cover:

Based on Six soil profile served characteristics, the soil site use/ soil cover identified are cultivated land, an it's delineated into single and double crop with mango and orange orchards based on temporal date, respectively, $CaCO_3$ nodules are present in weathered basalt on pedon P2 and P3 assured rainfall zone profile particularly.

The details about location of soil profile, name of soil series latitude and longitude, mean annual rainfall (MAR) in mm, mean annual temperature (MAT) in ^{0}C and physiographic/ topography drainage and slope are given in table1. The pedons P2, and P5 plateau in topography to be slightly undulating that of P3, P4 and P6 were subdued plateau. And pedon P1 are interhilly. The drainage were recorded to be 1-3 %, moderately well of all pedon except pedon P4.

Table 1 Soil Site characteristic of Pigeon pea growing on some Vertisols of Marathawada region of Maharashtra.

Soil series	Latitude	Longitude	MAR (mm)	MAT (^{0}c)	Land use	Drainage	Physiography	Remarks
Hadgaon P1	19^{0}16"34	76^{0}45"38	905.6	28.3	Double crop	M. Well	Plateau	Quartz and CaCO3 surface, 3-5 cm crack
Beed-P2	18^{0}95"48	75^{0}75"80	699.4	25.15	Double crop	M. Well	Plateau	3-5 cm cracks
Govindpur-P3	18^{0}63"96	76^{0}78"70	736.2	25.8	Double crop	M. Well	Subdued Plateau	1-2 cm cracks' with 40 cm
Wadgaon-P4	18^{0}28"68	76^{0}09"97	708.4	25.8	Single crop	Imperfect	Subdued Plateau of inter hill	No cracks
Latur P5	18 41"96	76 61" 84	743.5	26.7	Double crop	M. Well	Plateau	1-2 cm Crack's
Bharaswada-P6	19^{0}52"28	75^{0}69"89	747.9	27.2	Double crop	M. Well	Subdued Plateau	3-5 cm cracks

MAR-MeanAnnualRainfall*

* ***MAT-****MeanAnnual Temperature*

Morphological properties of Soil:

Morphological properties of soils indicated on table 2. Soil depth of the soils study area varied from 100 to 120 cm which corresponds to moderated deep. Pedons had their Munsell colour notation in the hue of (very dark gray to dark brows) (10 YR 3/1 to 10YR 5/1) the surface horizons of all the pedon generally had granular to sub- angular blocky structure and slightly hard to hard (dry) and friable to moderately friable (moist) condition and very sticky and very plastic in wet condition of consistency. These pedons ware associated with gravelly clay loam, clay loam to clay texture. The surface and sub-surface horizons of pedons are associated with sub-angular blocky statures of medium grades and sizes but angular blocky structure associated with slickenside is a common feature of sub-soils pedons P2, P3, P4, P5 and P6 except pedon P1 (Malode and Patil, 2014).

Table 2 Morphological properties of Pigeon pea growing on some Vertisols of Marathwada region of Maharashtra.

Pedon	Horizon	Depth (cm)	Matriccolour		Structure			Pressure faces SS/PF	Soil Consistency	Slope %
			Dry	Moist	Type	Grade	Size			
Hadgaon P1	Ap	0-15	10YR 5/1	10YR 4/1	m	2	sbk	--	vfi, vs, vp	0-3
	A	15-40	10YR 4/2	10YR 4/1	m	2	sbk	--	vfi, vs.vp	
	Bw	40-65	10YR 4/2	10YR 4/1	m	2	sbk	PF	vfi, vs.vp	
	Bssk	65-105	10YR 4/2	10YR 4/2	m	2	sbk/abk	SS	vfi, vs.vp	
Beed P2	Ap	0-15	10 YR 3/2	10 YR 3/3	m	2	sbk	-	vh, vfi, vs, vp	1-3
	A	15-27	10 YR 3/2	10 YR 3/3	m	2	sbk	-	vh, vfi, vs, vp	-
	Bw	27-60	10 YR 3/2	10 YR 3/1	m	2	sbk	PF	vh, vfi, vs, vp	
	Bssk	60-100	10 YR 3/1	10 YR 3/1	m	2	sbk/abk	SS	vh, vfi, vs, vp	
Govindpur P3	Ap	0-15	10 YR 3/1	10 YR 3/2	m	2	sbk	-	sh, vfi, vs, vp	2-3
	A	15-30	10 YR 3/1	10 YR 3/1	m	2	Sbk	-	fi, vs, vp	
	Bw	30-60	10 YR 3/1	10 YR 3/1	m	2	sbk	PF	vfi, vs, vp	
	Bssk	60-105	10 YR 3/1	10 YR 3/1	m	2	sbk/abk	SS	vfi, vs, vp	
Wadgaon P4	Ap	0-15	10 YR 3/3	10 YR 3/3	m	2	Sbk	--	sh, fi, vs, vp	1-3
	A	15-33	10 YR 3/2	10 YR 3/3	m	2	Sbk	--	fi, vs, vp	
	Bss1	33-65	10 YR 3/2	10 YR 3/3	m	2	Sbk	PF	vfi, vs, vp	
	Bssk	65-100	10 YR	10 YR	m	2	Sbk	SS	vfi, vs, vp	

			3/2	3/2						
Latur P5	Ap	0-25	10 YR 3/2	10 YR 3/2	m	2	Sbk	--	vh, vfi, vs, vp	1-3
	Bw1	25-60	10 YR 3/2	10 YR 3/2	m	2	Sbk	---	vh, vfi, vs, vp	
	Bw2	60-90	10 YR 3/1	10 YR 3/1	m	2	Sbk	PF	vh, vfi, vs, vp	
	Bssk	90-120	10 YR 3/1	10 YR 3/1	m	2	Sbk	SS	vfi, vs, vp	
Bharaswada P6	Ap	0-15	10 YR 3/3	10 YR 3/3	m	2	sbk	-	sh, fi, ns, vp	1-3
	A	15-35	10 YR 3/3	10 YR 3/3	m	2	sbk	-	fi, ns, vp	
	Bw	35-65	10 YR 3/2	10 YR 3/3	m	2	sbk	PF	vfi, vs, vp	
	Bssk	65-102	10 YR 3/2	10 YR 3/2	m	2	sbk/abk	SS	vfi, vs, vp	

Physical properties of soil:

Physical properties of soils were presented in table 3. Indicated that the coarse fragment in soils was varies from 9.7 to 62.1 per cent. The partial size distribution and sand/silt ratio show inflection in sand, silt and clay content in depth distribution and very significantly in soil having differed parent materials. It is also observed that the sand and silt ranged from 9.7 to 25.9 and 19.7 to 31.6 per cent respectively. The clay content ranged from 51.2 to 62.1 in varied pedons. It is also observed that the clay distribution below the profile for all soils was almost uniform suggesting of their development from their same kind of parent material under same climatic condition. These soils were developed on lower topographic position showed higher clay content as compared to soil developed on higher topographic position; topography and slope were found to affect the particle size distribution. Macro topography must have been played key role in the profile development (Pal *et al.,* 2000). The higher bulk density (1.56 Mg m^{-3}) was noticed in pedon P1 and the lowest (1.27 Mg m^{-3}) in pedon of P4. The bulk density, in general, increased with depth. The saturated hydraulic conductivity ranged from 0.2 to 5.3 cm hr^{-1} pedon P2 was found to be the poorly drained depth of soil which showed the low hydraulic conductivity which might be due to presence of Mg^{2+} in the subsurface origin and variation may be attributed to textural variation. In general the low hydraulic conductivity was decreased with depth (Kadu *et. al.,* 2003).

Table. 3 Physical properties of Pigeon pea growing on some Vertisols of Marathwada region of Maharashtra

Pedon	Horizon	Depth (cm)	SHC (cm hr^{-1})	Bulk density (Mg m^{-3})	Particle size distribution (%)			Textural class
					Sand	Silt	Clay	
Hadgaon P1	Ap	0-15	0.5	1.52	15.8	27.1	57.1	c
	A	15-40	1.0	1.54	12.8	28.7	59.2	c
	Bw	40-65	0.4	1.56	16.7	31.8	51.2	c
	Bssk	65-105	1.9	1.55	9.7	28.3	62.1	c
Beed P2	Ap	0-15	2.3	1.48	16.8	30.1	53.1	c
	A	15-27	2.8	1.51	14.6	29.8	55.6	c
	Bw	27-60	1.1	1.53	20.6	27.6	51.8	cl
	Bssk	60-100	0.2	1.53	16.1	25.1	58.9	cl
Govindpur P3	Ap	0-15	4.7	1.36	17.2	31.6	51.2	c
	A	15-30	5.3	1.41	16.1	31.1	52.7	cl
	Bw	30-60	1.9	1.39	15.8	29.1	55.1	cl
	Bssk	60-105	0.9	1.29	14.2	27	58.8	cl
Wadgaon P4	Ap	0-15	2.5	1.29	19.8	28.1	52.2	c

	A	15-33	2.7	1.32	17.9	28.4	53.7	c
	Bss1	33-65	0.9	1.36	16.2	28.2	55.6	c
	Bssk	65-100	0.4	1.27	14.9	27.8	57.3	cl
Latur P5	Ap	0-25	1.0	1.30	21.6	28.4	50.1	c
	Bw1	25-60	1.4	1.31	18.03	30.27	51.7	c
	Bw2	60-90	1.1	1.40	16.1	30.8	53.1	c
	Bssk	90-120	0.9	1.42	15.8	28.3	55.8	cl
Bharaswada P6	Ap	0-15	1.3	1.37	19.9	23.4	56.7	c
	A	15-35	2.0	1.48	15.6	26.8	57.8	c
	Bw	35-65	0.9	1.47	18.2	27.1	54.7	c
	Bssk	65-102	0.4	1.32	10.2	30.7	59.3	c

Chemical properties of soil:

The pH of the soil is slightly alkaline to moderately alkaline with pH ranging from 7.8 to 8.7. The electrical conductivity varied from 0.204 to 0.635 dSm^{-1}. Which well below the medium to high permissible limits in table 4.

The Soil organic carbon and total carbon content ranged from 0.195 to 0.994 and 0.789 to 2.689 (%) in different horizons of pedons and in general, decreased with depth. but, in total carbon content had increased with depth of all profile. It may be effect of pedogenic and non pedogenic present of calcium carbonate it may inorganic form of carbon. This might be due to sieving effect and adsorption of fine organic particles, water soluble organic matter and it maybe effect of fallow land respectively by soil particles.

The soil microbial biomass carbon (SMBC) and CO_2 evolution varied among the pedons and were generally higher in the surface horizons (Table 4). The SMBC values in surface soils ranged from **294.04 to 870.23 µg kg^{-1},** with the highest value observed in **Pedon P3 (Govindpur)** followed by **P5 (Latur)** and **P6 (Bharaswada),** whereas the lowest value was recorded in **Pedon P2 (Beed).** Similarly, CO_2 evolution ranged from **4.4 to 10.0 mg CO_2 kg^{-1} soil 24 hr^{-1},** with relatively higher values in pedons having greater organic carbon content. The higher SMBC and CO_2 evolution in surface horizons may be attributed to higher availability of organic substrates and favourable conditions for microbial activity, while lower values in subsurface layers may be due to reduced organic matter and microbial population. The results indicate that microbial biomass and soil respiration are closely related to soil organic carbon content and biological activity of soils. Similar observations were reported by Vance E. D. *et al.* (1987) and Anderson J. P. E. and Domsch (1989), who reported that microbial biomass and soil respiration are strongly influenced by organic matter and nutrient availability in soils.

The calcium carbonate content varied from 2.8 to 19.0 %. The high calcium carbonate in soil affect the water holding capacity of soil which has great bearing on crop production under rain fed condition. Calcium carbonate affects the physical and chemical characteristics of soil and may prevent root penetration (Sys; 1985). The high cation exchange capacity is attributed to the high amount of clay. The CEC ranged from 38.2 to 62.5cmol $^{(P+)}$ kg^{-1}. The cation exchange capacity of these black soils is attributed to its smectitic clay mineralogy (Pal and Deshpande, 1987). Since soils under study had low to moderate organic carbon status, clay fraction appeared to influence largely the CEC value (Pal *et, al.,* 2000).

Table 4. Chemical properties of Pigeon pea growing on some Vertisols of Marathwada region of Maharashtra

Pedon	Horizon	Depth (cm)	pH	EC (dSm-1)	SOC (%)	TC (%)	SMBC (µg kg -1)	CO_2 (mg CO_2 kg -1 24 hr -1)	$CaCO_3$ (%)	CEC cmol (p+) kg-1
Hadgaon P1	Ap	0-15	8.4	0.635	0.624	1.524	376.90	4.9	7.5	45.5
	A	15-40	8.7	0.444	0.507	2.199	128.17	6.8	14.1	47.3
	Bw	40-65	8.4	0.591	0.351	1.287	--	--	7.8	66.2
	Bssk	65-105	8.5	0.600	0.195	2.463	--	--	18.9	38.2
Beed P2	Ap	0-15	8.0	0.270	0.624	1.116	294.04	4.4	4.1	59.2
	A	15-27	7.8	0.286	0.585	1.005	120.13	8.8	3.5	62.1
	Bw	27-60	8.1	0.231	0.562	1.594	--	--	8.6	62
	Bssk	60-100	7.9	0.261	0.331	1.675	--	--	11.2	59.1
Govindpur P3	Ap	0-15	8.1	0.254	0.994	1.570	870.23	7.0	4.8	45.4
	A	15-30	8.5	0.288	0.624	1.536	313.70	8.6	7.6	47.1
	Bw	30-60	8.3	0.346	0.524	1.604	--	--	9.0	51.6
	Bssk	60-105	8.4	0.560	0.292	1.612	--	--	11.0	41.3
Wadgaon P4	Ap	0-15	8.0	0.233	0.975	2.115	404.79	5.7	9.5	48.9
	A	15-33	7.9	0.269	0.721	2.041	208.72	9.1	11.0	51.5
	Bss1	33-65	7.9	0.204	0.546	2.442	--	--	15.8	56.3
	Bssk	65-100	8.1	0.290	0.409	2.689	--	--	19.0	40.3
Latur P5	Ap	0-25	8.1	0.290	0.682	1.018	669.45	10.0	2.8	55.8
	Bw1	25-60	8.1	0.291	0.624	1.08	786.20	6.8	3.8	52.1
	Bw2	60-90	8.0	0.287	0.429	0.789	--	--	3.0	62.5
	Bssk	90-120	8.3	0.337	0.351	0.951	--	--	5.0	40.5
Bharaswada P6	Ap	0-15	8.1	0.255	0.741	1.437	602.49	6.1	5.8	51.2
	A	15-35	8.0	0.230	0.641	1.301	218.51	7.0	5.5	54.7
	Bw	35-65	8.1	0.237	0.292	1.672	--	--	11.5	61.1
	Bssk	65-102	8.2	0.227	0.195	2.211	--	--	16.8	41.5

Nutrient status of soils:

The available N, P and K ranged from 51.2 to 334.8, 1.00 to 27.10 and 272.6 to 583.8 Kg ha^{-1}, respectively in different pedons and in general, their content decreased with the depth table 5. The variation in available N content in soil could be attributed to the differences in their physiographic, differential cultivation and management practices of this soil but also removed of N by the crop, losses through leaching, denitrification, fixation and volatization take place. Some nitrogen is immobilized by soil microbes. These results were in confirmatory with result reported by Malewar *et.al.* (1998). the availed N was optimum in A horizons of P4 and low in P6 were as deficient in profile. Available P was optimum in surface horizon of P4 and low to defiance in other pedons and K was above optimum at P4 and low in P1.

The DTPA-Fe ranged from 3.00 to 7.11 mg kg^{-1} Table5 and found to be medium to higher than the critical level of 4.5 mg kg^{-1} (Lindsey and Norvell 1978) in all the soils. DTPA-Mn varied from 2.36 to 21.89 mg kg^{-1} and found to much higher than critical level of 3.0 mg kg^{-1} (Takkar *et. al.* 1989) in all the soils. DTPA-Zn of all soils pedon varied from 0.41 to 1.39 mg kg^{-1} the deficient in Zn as per critical level of 0.6 mg kg^{-1}which, was also reported by (Sharma *et. al.*1996; Patil. 2013and Malode and Patil., 2014). DTPA-Cu of the soil ranged from 0.59 to 4.51 mg kg^{-1} and decreased with depth but higher than the critical value of 0.2 mg kg^{-1} in all the soils (Katyal and Randhawa 1983).

Soil pH is the most important factor regulating Zn supply in calcareous soils. At alkaline pH, very low levels of soluble Zn are found, and only a negligible amount can be in there from of exchangeable Zn^{++}, which is available to plant and need to be supplemented (Patricia 2000).

Table 5. Nutrient status of Pigeon pea growing on some Vertisols of Marathwada region of Maharashtra

Pedon	Horizon	Depth (cm)	Available macro nutrient (kg ha^{-1})			Available micronutrient (mg kg^{-1})			
			N	P	K	Fe	Mn	Zn	Cu
Hadgaon P1	Ap	0-15	103.5	10.60	519.9	5.17	14.18	0.90	2.13
	A	15-40	222.7	4.60	303.9	3.90	12.37	0.81	1.98
	Bw	40-65	65.9	2.20	229.6	4.13	8.87	0.82	1.72
	Bssk	65-105	62.7	1.20	294.1	3.29	4.98	0.51	1.67
Beed P2	Ap	0-15	259.9	18.20	318.2	6.13	21.89	1.23	2.61
	A	15-27	125.4	2.80	404.7	4.20	14.39	0.92	3.11
	Bw	27-60	94.9	1.20	350.3	3.17	12.94	0.92	2.16
	Bssk	60-100	74.4	1.00	272.6	3.00	8.39	0.49	1.67
Govindpur P3	Ap	0-15	128.5	16.30	403.8	5.91	12.81	0.93	4.13
	A	15-30	134.8	8.90	427.1	4.76	13.80	1.11	4.12
	Bw	30-60	97.2	3.10	348.2	3.93	2.36	0.81	4.23

	Bssk	60-105	87.8	2.00	382.5	3.51	3.09	0.61	2.22
Wadgaon P4	Ap	0-15	206.9	27.10	583.8	6.20	15.42	1.39	3.90
	A	15-33	334.8	11.20	472.1	5.53	12.83	0.91	4.10
	Bss1	33-65	128.5	1.60	461.2	4.18	6.40	0.61	2.56
	Bssk	65-100	63.9	1.40	382.3	3.81	7.51	0.51	1.75
Latur P5	Ap	0-25	213.2	21.20	465.8	5.52	15.66	0.91	2.83
	Bw1	25-60	194.3	6.50	438.9	5.10	12.13	0.68	3.10
	Bw2	60-90	140.1	2.80	382.7	4.37	8.17	0.49	2.01
	Bssk	90-120	90.7	1.80	337.5	3.18	6.42	0.46	0.59
Bharaswada P6	Ap	0-15	219.1	10.20	523.4	7.11	16.80	1.32	4.51
	A	15-35	75.4	3.40	469.5	6.27	16.15	1.13	3.98
	Bw	35-65	69.0	1.80	373.2	4.14	13.04	0.82	1.77
	Bssk	65-102	51.2	1.20	291.4	4.01	10.48	0.41	1.98

Soil classification and Soil site suitability for Pigeon pea crops:

The soil–site suitability evaluation for pigeon pea crop was carried out using the criteria suggested by Sys et al. (1991) and modified by National Bureau of Soil Survey and Land Use Planning (NBSS & LUP, 1994). The results of suitability evaluation along with the observed yield of pigeon pea are presented in Table 6. The pedons of the study area showed variation in suitability classes due to differences in soil depth, organic carbon content, hydraulic conductivity and calcium carbonate. Pedon P1 (Hadgaon) was classified as marginally suitable (S3) according to the parametric evaluation method mainly due to limitation of low soil organic carbon. However, based on the actual yield obtained (11.9 q ha^{-1}), representing 59.5% of optimum yield, the soil was categorized as moderately suitable (S2) according to the productivity index approach suggested by Food and Agriculture Organization (FAO, 1983). Similarly, pedon P2 (Beed) was rated as moderately suitable (S2) with limitations of hydraulic conductivity and organic carbon. The recorded yield of pigeon pea was 11.2 q ha^{-1}, corresponding to 56.0% of the optimum yield, which also placed the soil in the S2 suitability class.

Pedon P3 (Govindpur) was classified as marginally suitable (S3) mainly due to organic carbon limitation. However, the observed yield of 15.2 q ha^{-1}, representing 76.0% of optimum yield, indicated moderate suitability (S2) for pigeon pea cultivation. Pedon P4 (Wadgeon) was evaluated as moderately suitable (S2) due to limitations of calcium carbonate and organic carbon, although yield data were not available because pigeon pea was not regularly cultivated in that location. Pedon P5 (Latur) was also categorized as moderately suitable (S2) due to moderate limitation of soil organic carbon. The recorded yield of 14.8 q ha^{-1} (74.0% of optimum yield) confirmed its moderate suitability for pigeon pea cultivation. Among the studied soils, pedon P6 (Bharaswada) showed relatively higher productivity with a yield of 16.9 q ha^{-1}, which corresponds to 84.5% of the optimum yield, and therefore was classified as highly suitable (S1) for pigeon pea cultivation based on yield performance.

The results clearly indicate that deep Vertisols with better soil depth, higher clay content and greater moisture retention capacity provide favourable conditions for pigeon pea cultivation, whereas soils with lower organic carbon and other physical limitations reduce crop productivity. These findings are in agreement with earlier studies which reported that soil depth, moisture availability and organic carbon significantly influence pigeon pea productivity in semi-arid regions (Patil et al., 2018; Kumar et al., 2020).

Table 6. Soil site suitability classes and yield of Pigeon Pea growing on some Vertisols Marathawada region of Maharashtra

Pedon	**Sys *et.al.*, (1991) and NBSS & LUP (1994) Pigion Pea**	**Soil site suitability class with limitation (FAO.1983)**		
		Yield q/ha^{-1}	**% Yield optimum yield (25 q ha^{-1})**	**Suitability Class**
Hadgaon P1	S3 (o)	11.9	59.5	S2
Beed- P2	S2 (h,o)	11.2	56.0	S2
Govindpur- P3	S3 (o)	15.2	76.0	S2
Wadgeon- P4	S2 (k,o)	--	--	S2
Latur- P5	S2 (o)	14.8	74.0	S2
Bharaswada-P6	S3	16.9	84.5	S1

** Latter in parentheses show limitation as, dt-soil depth, s- slope, o-organic carbon, k-CaCO3, h-hydrolic conductivity and p- pH.*

** Suitability class – S1- Highly suitable, S2- Moderately suitable, S3- Marginally suitable, N1- Currently not suitable & N2- Un suitable.*

**The yield was notated in mean of 5 years (*-- Not regular sowing).*

CONCLUSION

The soils of the Marathwada region were characterized by moderately deep to deep profiles developed from basaltic parent material and dominated by clay-rich Vertisols. Variations in soil physical properties such as clay content, bulk density and hydraulic conductivity were influenced by topography and parent material. The soils were slightly to moderately alkaline with moderate to high cation exchange capacity due to smectitic clay mineralogy.

Soil organic carbon, soil microbial biomass carbon (SMBC) and CO_2 evolution were generally higher in the surface horizons, indicating greater microbial activity associated with organic matter availability. The nutrient status showed low to medium levels of available nitrogen and phosphorus, while potassium was relatively higher. Micronutrient analysis indicated adequate levels of Fe, Mn and Cu, whereas zinc deficiency was observed in some pedons due alkaline to moderately alkaline in soil conditions.

Land suitability evaluation revealed that soil depth, organic carbon content, hydraulic conductivity and calcium carbonate were the major factors influencing pigeon pea productivity. Vertisols with greater moisture retention capacity showed higher suitability and productivity, whereas soils with physical and fertility limitations were moderately to marginally suitable. The study emphasizes the importance of soil characterization and appropriate nutrient management for sustainable pigeon pea cultivation in the semi-arid regions of Marathwada.

REFERENCES

1. Anonymous. 1983. Guidelines for Land Evaluation for Rainfed Agriculture. FAO Soils Bull., 52, Rome, pp.237.
2. Anonymous (1986). The soils of Mondha village (Nagpur) for Agrotechnology transfer, Soil Bull., NBSS&LUP publ. p. 65.
3. Anonymous. 1994b. Soil Trxonomy. USDA-SCS Agril.Handb.436, U. S. Govt. Printing Office, Washington, D. C. pp.436.
4. Anonymous.1994a. Proceedings-National Meet on soil-site suitability Criteria for different crop, Feb. 7-8 at Nagpur, NBSS and LUP Publ. pp.22.
5. Bhaskar, K.S., Lal, S., Chall, O. and Madavi, S.H. (1987). Effect of soil depth on cotton yield. Journal of the Maharashtra Agricultural Universities 12(1): 139- 40.
6. Black, C.A., Evans, D.D., Ensminger, L.E., White, J.L. and Clark, F.E. (Eds) 1965. Methods of soil analysis Part-I, Am. Soc. Agron.Inc. Publisher Madison, Wisconsin, USA.
7. Chopra, S. L. and Kanwar, J. S., 1976, Analytical agricultural chemistry, Kalyani ublishers, New Delhi.
8. Deshmukh SN, Bapat MV. 1993 Land evaluation for different uses. J Indian Society of Soil Science. 41:202-204.
9. Eswaran H, Gathrie RL. 1982. International technical assistance in soil survey and classification abstract. Valuntary paper 12th international congress of soil sciences. New Delhi. India,.
10. FAO, 1976.AFramework for Land Evaluation.Soils Bull, 32, FAO, Rome. pp236.
11. Garud, H. S., Asewar, B. V., Chavan, A. A., Gokhale, D. N., & Narkhede, W. N. (2021). Production potential of pigeon pea based intercropping systems under various land configurations in Marathwada region of Maharashtra. Legume Research, 44(8), 947–951. doi:10.18805/LR-4398
12. Hilgard, E. 1906. Soils, their formation, properties, compositions, and relations to climate and plant growth in the humid and arid regions. MacMillan, New York, New York, USA. 20 (3):pp 330-337.
13. Jackson, M.L. 1973. Soil Chemical Analysis, Prentice Hall of India Pvt. Ltd., New Delhi.27 (1):pp117-119.
14. 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 Vertisals for deep-rooted crops in semiarid part of central India.Soil Use and Management. 19: pp 208-216.
15. Katyal, J.C. and N.S. Randhawa. 1983. Micronutrients. FAO Fertilizer and Plant Nutrition Bulletin 7. Rome: Food and Agriculture Organization of the United Nations. 42 (6); pp165-174.
16. Kuhad, M.S. and Karwasra, S.P.S. (1991). Soil potential ratings for sugarcane in an operational area of sugar factor Palwal, Haryana. Journal of the Indian Society of Soil Science 39(1) : 147-153.
17. Lindsay, W. L. and W. A. Norvell, 1978. Development of DTPA soil tests for zinc, iron, manganese, and copper. Soil. Sci. Soci. American J., 42: pp 421 – 428.
18. Malewar, G.U., Sayed Ismail and Rudraksha G.B. 1998. Intergratednitrogen management in Chilli (Capsiumannuml.) Bull. Indian Insti. Soil Sci.,2: pp156-163.
19. Malode, K. R. 2014. Soil organic carbon mapping of Agro-ecological zones of Marathwada region of Maharashtra state. Thesis submitted to Vasantrao Naik Marathwada Krishi Vidyapeeth Parbhani.(MS)India.
20. Malode, K. R. and Patil, V. D. 2014.Characterization of some Vertisols of Drought prone zone of Marathwada region. Asian J. Soil. Sci., 9(1): pp137-141.

21. NBSS & LUP 1994.Proceedings of national meeting on soil-site suitability criteria for different crops.Feb. 7-8, Nagpur, India pp 20.

22. Pal, D.K., Deshpande, S.B., Velayutham, M., Srivastava, P. and Durge, S.L. 2000.Climatic change and polygenesis in Vertisols of Purna Valley (Maharashtra) and their management. Res. Bull. NBSS Pub.No.83.

23. Pal, D.K. and Deshpande S.B. 1987. Characteristics and genesis of minerals in some benchmark Vertisols of India. Pedologe, 37: pp259–275.

24. Patil,V. D., 2013.Assessment of chemical and biochemical indices for diagnosing Zn deficiency and soil associated factors of citrus (Citrus sinensis L. Osbeck) nutrition. Acta horticulture (ISHS).984:pp297-305.

25. Patricia, I. (2000). Integrated Nutrient Management for Sustaining Crop Yields in Calcareous Soils. GAU-PRII-IPI National Symposium on 'Balanced nutrition of groundnut and other field crops grown in calcareous soils of India' held at Junagadh, Gujarat, India from September 19-22,

26. Patiram, Upadhyaya, R.C.; Sing, C.S. and Munna, R. 2000.'Micronutrient cation status of mandarin (Citrus reticulataBlanco) orchard of Sikkim.In J. Indian Soc. Soil Sci., 48: pp 246-249.

27. Ramamurthy, V., Mamatha, D., Niranjan, K. V., Vasundhara, R., Ranjitha, K., Chandrakala, M., & Singh, S. K. (2019). Suitability evaluation for pigeon pea in southern transition zone of Karnataka Plateau, India. Legume Research, 43(6), 812–818. doi:10.18805/LR-4047

28. Requier, J. Bramao, D.L. and Cornet, J.P. 1970. In new System of soil Appraisal in Terms of Actual and potential Productivity, FAO-Adltesr 7017, Rome, pp 426.

29. Sharma, S.S., Totawat K.L. and Shyampura, R.L. 1996.Characterization and classification of soils in a toposequence over basaltic terrain. J. Indian Soc. Soil Sci. 44(3): pp 470-475.

30. Shaloo, H., Bisht, H., Jain, R., & Singh, R. P. (2022). Cropland suitability assessment using multi criteria evaluation techniques and geo-spatial technology: A review. The Indian Journal of Agricultural Sciences, 92(5), 554–562. doi:10.56093/ijas.v92i5.124622

31. Srivastava, R., Omprakash and Sharma, A.K. (1991). Influenced of soil and management on growth and yield of wheat in foot hill region of Uttar Pradesh. Journal of the Indian Society of Soil Science 39(2) : 374- 376.

32. Soil Survey Staff. 1975. Soil Taxonomy. USDA-SCS Agril.Handb.436, U.S. Govt. Printing Office, Washington,D.C. pp 436.

33. Soil Survey Division Staff. 2000. Soil Survey Manual (Indian Print), USDA Handbook 18, US Govt. Printing Office, Washington,

34. Soil Survey Staff.1998. Keys to Soil Taxonomy, 8thEdition. SCS,USDA,Washington,DC.pp 338.

35. Subbiah, B.V. and Asija, G.L. 1956.A rapid procedure for the estimation of available nitrogen in soils.Curr. Sci. 25: pp 259-260.

36. Sys, C. 1985. Land Evaluation Part I, II, III State Univ. Ghent Publ., Belgium, pp 274.

37. Sys, C., Van Ranst, E. and Debaveye, J. 1991.Land Evaluation Part I, II. Red-edited valums of publication no. 7 of the general Administration of Cooperation Development, Brussels, Belgium, pp 274.

38. Takkar, P.N. 1996. Micronutrient research and sustainable Agril.productivity in India. J. India Soc. Soil. Sci., 44(4): pp 562-581.

39. Technical manual U.S.E.P.A. 2001. Methods for collection, storage and manipulation of sediments for chemical and toxicological Analyses: Technical manual U.S. Environmental protection Agency Washington, D.C. 20460.

40. Upadhyaya, H.D., Kashiwagi, J., Varshney, R.K., et al. (2012). *Phenotyping chickpeas and pigeonpeas for adaptation to drought.* **Frontiers in Plant Physiology**, 3, 179, pp. 1–10. DOI: 10.3389/fphys.2012.00179.

41. Vance, E. D., Brookes, P. C., and Jenkinson, D. S. 1987. **An extraction method for measuring soil microbial biomass carbon.** *Soil Biology and Biochemistry*, **19(6)**: 703–707.

42. Waikar, S. L., Malewar, G. V. and Kausadikar H. K. 2003. Characterization and classification of soils of drought prone south central part of Maharasthra. j. Soils and Crops13 (2) pp 262-266.

43. Walkley, A. and I. A. Black. 1934. An examination of Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Sci. 37: 29-37.