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Landscape planning for agridevelopment at regional scale: an example from cotton growing Yavatmal district, Maharashtra, India

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Abstract: The basaltic landscape planning on the hot semiarid ecosystem in cotton growing Yavatmal district, Maharashtra tends to concentrate on 52 per cent of total cultivated area with 43 per cent of rural families living below poverty line posing major problem for environmental protection and resource management. Concepts of sustainable development at regional level planning suggested that there is a growing concern for the landscape community to develop a strategic regional agricultural planning perspective in order to assist landscape planning goals. These challenges were explored with particular reference to the cotton growing Yavatmal district in Maharashtra through baseline land resource / agronomic surveys and assessing the production potential of regional rural landscapes for crop planning. Landscape analysis, premised on the geopedological and elevation constructs, culminated in a spatial coverage of hills and ridges (12.6 per cent of total area) in northern and central parts whereas plateaus (29.3 per cent) in association with isolated hills, mesas and butte and escarpments (17.7 per cent), pediplains (28.8 per cent) and plains (8.1 per cent) in south western parts of the district.The arability and suitability analysis showed that 25.04 per cent of area is evaluated as suitable for cotton under dryland conditions with fertilizer dose from 123 kg/ha to 141.56 kg/ha of nitrogen and 64 to 83kg/ha of phosphorus and 51 to 69 kg/ha of potassium in the region. Regional level analysis revealed spatially variable soil typologies dominated by vertisols and vertic intergrades. An exploration and brief account of integration of landscape planning was discussed with some reflections on the experience and highlighting some of the problems and potentials of this approach within the regional context.

Key words: landscape planning, cotton, Yavatmal district, shrink – swell soils

Introduction

Landscape is often referred as an integrating, holistic concept, which provides common ground for diverse disciplines, and actors to address shared problems (Fry, 2001; Nave, 2001; Tress *et al.*, 2003). Landscape is considered as one of the arenas of convict due to diversity of interests for limited resources. The landscape approach is broadly divided into two stages viz., characterization, and judgment. The land characterization is seen as dining, and describing the landscape character areas and types. This first stage comprises a desk study, where an initial understanding of the landscape is attained primarily through map analysis and preparation of overlays of different aspects, providing the context for draft landscape character areas/types. This is followed by a field study, which involves identifying the sensory elements, refining boundaries and corroborating desk study information. Classification brings together information of the landscape before dividing it into distinct recognisable areas and types with consistent common character.

Agricultural landscapes are functionally as well as structurally, clear expressions of the interaction between nature, and society as well as being centrally located between global drivers of change, and local socio-ecological conditions (Kites *et al.*, 2001). Recent years have witnessed a proliferation of research on the impacts, tradeoffs, and ramifications of rural land-use management relative to the set of social, and ecological goods, and services that society demands from landscapes, including food and fiber production, biodiversity conservation, ecosystem service delivery, poverty alleviation, and economic development (Tscharntke *et al.*, 2012). The scale and severity of agricultural impacts on ecological systems, as well as the formidable challenge of designing management approaches to meet escalating global demands for food production, and ecosystem services in the context of limited land, and water resources, climate change, and widespread ecosystem degradation (Ellis *et al.,* 2010). A parallel stream of work has elaborated a variety of landscape analysis, planning and management approaches to address some of these challenges (De Groot *et al.,* 2010). Land management for cotton production (including food production) is a widespread policy issue of this paper in the context of changing agricultural structures and functional activity at regional scale. FAO methodology were widely applied in land evaluation for cotton suitability in Kardista (7500hectares) of Central Greece having soils of entisols, inceptisols, alfisols and vertisols (Kollias. and Kalivas, 1999), and of aridisols in Al_Jezira Irrigation Project Nineveh - Iraq by AlYaa Quby (2011). Likewise in India , several attempts were made in suitability of evaluation of shrink-swell soils for cotton in parts of Central india. The soil-site evaluation for cotton showed the limitation of soil depth, and slope in Ringanbodi watershed, Nagpur district, Maharashtra (Walke *et al.,* 2012) and in the toposequences of Girnar region of Gujarat were reported (Gandhi *et al.,* 2013) whereas saturated hydraulic conductivity was reported to be a major factor limiting cotton productivity in shrink-swell of India (Kadu *et al.*, 2003). The cotton suitability analysis of Mansa district of Punjab State was attempted based on the soil parameters, quality of ground water and soil fertility status using Saaty's method in the ARC/INFO GIS environment (Kalubarme *et al.*, 2013). Later , some proposal were made to improve land capability index, and Sys parametric method in abberant rainfall conditions as witnessed in Central peninsular region of India (Venugopalan *et al.*, 2003 and Mandal *et al.*, 2010). The importance of climate for cotton based systems in the region is critically analysed and reported that the rainfall of 250 to 325 mm from squaring to peak flowering stage was found to be critical (Mandal *et al.,* 2005). Hence climate of Yavatmal for cotton is moderately suitable with short dry spells at critical stages during September to October . The region experiences 12 to 20 normal dry weeks followed by 3 to 8 wet weeks from 35 years of daily rainfall data using standardized precipitation index (Bhaskar *et al.*, 2014). This region is a hotspot for critical analysis of land use activity where economic dependence of farmers is solely on cotton. The poor agricultural productivity and low level of food grain outputs resulting from the low level introduction of agricultural/crop technologies; poor rural infrastructure; high vulnerability of crop production to natural disasters such as droughts and high rates of unemployment, and poverty, are some of the reasons for the high degree of food insecurity in some parts of the district.

It is increasingly understood that cotton growing areas of Vidharbha region are experiencing decline in cotton productivity because of inadequate use of land as per its capability and suitability. This understanding has in turn emphasized the need for more strategic approach to environmental planning at regional levels to support land use activity at the local and site scales. As a consequence, the region is increasingly being seen as an important scale for sustainable planning and management. This paper explores these challenges with particular reference to experience in the cotton growing Yavatmal district through the land resource and agronomic surveys to produce regional agricultural landscape planning strategy as the forefront of sustainability of crop planning in the region.

Study area

The cotton growing Yavatmal district (19^{0}26' to 20^{0}42'N latitude and 77^{0}18' to 79^{0}98'E longitude, Figure 1) has 13582 sq. km (4.41%) of the state with a population of 20,77144 (2.63% of the state). Forty three per cent of rural families are below poverty line under the masses of hilly country broken by broad valleys and by plains of Wardha and Painganga rivers. Yavatmal district comes under Deccan Plateau, Hot Semi-Arid Eco-Region (6) Western Maharashtra plateau, hot moist semiarid eco - subregion (6.3) (Velayutham *et al.*,1999). The mean annual rainfall varies from 1,125 mm of rain in eastern parts of Wani to 889 mm in western parts of Darwha, and 1099.5 mm in central portion of Yavatmal showing an increasing trend as one proceeds from west to east. The week wise SPI values were calculated during crop calendar for 35 years (1971 to 2005), and categorized into 6 classes. The near normal

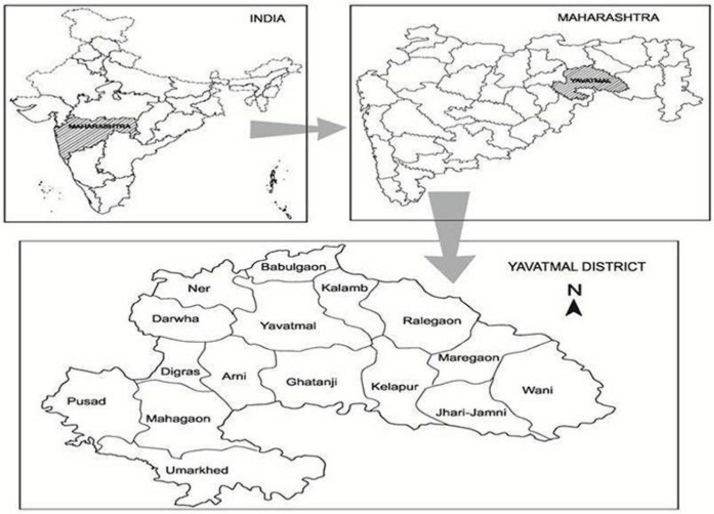

Figure 1 - Location map of Yavatmal district, Maharashtra.

dry periods are 63 % followed by 19.73% of normal wet periods, 5.71% of severely wet periods, 4.72% of moderately wet periods, 4.28% of extremely wet periods, and 2.41% of moderately dry weeks. The occurrence of prolonged dry spells during critical cotton growth stages (branching and flowering stages) often coincides, and causes reduction in yield. This region experiences maximum temperature more than 40^0C during April and May with decreasing trend from 36.5^0C in June to 28.5^0C in December with variations of ± 0.28^0C to ± 0.51^0C over period of 35 years (1971 to 2005). The temperature during June to December is ideal for growing cotton in the region (Abira, 2015). The seasonality index based on rainfall pattern was reported more than 1 indicating occurrence of most of the rain in three months(July, August and September) or less (Guhathakur and Saji, 2013).

The district has 34.4 per cent of cultivated land under food crops, and 52.19 per cent under fiber crops showing minimum per cent of area under food crops in Jhari Jamini tehsil (23.35%), and 31.2 % of area under fiber crops in Umarkhed tehsil. The landholding of 2-5 ha constitutes 40.12 % of entire district followed by 28.26% of 5-10ha holding. The total cultivated land is 8.84 lakh ha with double cropped area of 9475 ha, and a cropping intensity of 101%. The low cropping intensity indicates that the rainfed farming is prevalent in the entire region with little area under double cropped area. Yavatmal being predominantly agricultural district supports the agricultural population of 85 per cent. The economic progress of this district has always meant some progress in the agricultural sector. Paradoxically, the district is less efficient in agriculture due to low fertility of soils and basaltic plateau type of terrain attributes. The economic crisis of cotton growers in the region is forcing farmers to commit suicides due to steadily increasing cost of Bt cotton cultivation approximately Rs. 7,000 to 8,000 for non-irrigated land and Rs. 15,000 to 16,000 for irrigated land.

Methodology

Agro geographic analysis

The agro geographic analysis was carried out using the district statistical data of the year 2006-2007(Government of Maharashtra, 2006-07) as base year to calculate various index values for zonation of generic regions. The index of crop concentration was expressed as location quotient as given under:

LQ (location quotient) = $A_{ij}/A_j / \sum A_{ij}/\sum A_j$

where A ij = Gross cropped area under i^{th} crop in j^{th} tehsil, A j = Gross cropped area in j^{th} tehsil, Σ Aij = Gross cropped area under i^{th} crop in the District, $\sum$Aj = Gross cropped area in the district (Bhatia, 1965). When the index value greater than unity, signifies the areal unit concentration has great agricultural significance in deriving crop combinations in the region.

Land resource survey and GIS analysis

The reconnaissance soil survey in Yavatmal district on working scale of 1:50000 was worked out with visually interpreted Indian Remote Sensing Satellite (IRS – P6) imageries of same scale and constructed the pedo - geomorphological map. The field description and soil sampling were the most important works to determine the exact soil series on each of landscape unit (Soil Survey Staff, 2006). The sample from each layer of the soil profile were collected for analysis of physical and chemical properties as per standard procedures. The particle size analysis was done as per international pipette method described by Sarma *et al.* (1987). The chemical analysis where in P^H, electrical conductivity, organic carbon, calcium carbonate, exchangeable bases and cation exchange capacity (CEC) were determined as per procedures described by Jackson (1973). DTPA extractable micronutrients were determined as per Lindsay and Norvell (1978), available N by Subbiah and Asija (1956), P by Olsen *et al.* (1954) and exchangeable K (Schollenberger and Simon, 1954).

Soil –Site Suitability for cotton

The methodology used for the evaluation refers to the Sys *et al.* (1991) parametric method based on land evaluation framework for rainfed agriculture (FAO, 1983). The main step of this methodology was matching land characteristics against crop needs, giving in that way suitability rating for each land characteristics. The scheme of suitability for crops under study was done at two levels of classification such as order and class and assessed separately for each kind of land use under consideration with respect to arable soil mapping units. At the order level, the mapping units were grouped as suitable "S" and not suitable "N". At subclass level, the degree of suitability within the order was defined as S1- highly, S2- moderately and S3- marginally where as two subclasses were defined with the order – Not suitable as N1- currently not suitable and N2 - permanently not suitable. Brief outline of soil-site suitability evaluation for cotton was presented as under :

Soil- site parameters	Suitability classes				
	S1		S2	S3	N1
	Limitation level				
	0	1	2	3	4
Slope(%)	0-1	1-3	1-3	3-5	5-8 or more
Drainage	Well	Well	Moderately well drained	Imperfectly drained	Poorly to very poorly drained
Texture	clay, silty clay	clay silty clay, silty clay loam	Loam, silty loam, sandy clay loam	Sandy loam, loamy sand	sandy
Coarse fragments (%)					
Within 50cm	< 5	5-15	15-40	40-75	>75
Below 50cm	5-15	15-40	40-75	>75	-
Effective rooting depth(cm)	120	120-80	80-50	50-25	<25
Available water holding capacity (mm/m)	200	200-150	150-100	100-50	<50
$CaCO_3$ (%)	10	10-20	20-30	30-40	>40
ECe(dSm^{-1})	2-	2-4	4-8	8-15	>15
ESP(%)	5	5-10	10-15	15-25	>25

In particular in the first parameter slope and rock outcrops were considered, and for soil the coarse fragments, drainage, depth, pH, organic matter, the texture, $CaCO_3$ and the ECe were used in evaluation. Soil depth was performed according to the root depth described as control section of each crop. The analytical and field survey data were combined to form the attributed data of the GIS layer so as to generate soil map and worked out soil units suitable for cotton (Sehgal, 1991 , NBSS&LUP, 1994 and Naidu *et al.,* 2006). For each soil characteristic (i.e. a soil property that can be measured or estimated) used, the values that form the boundaries between suitability classes were determined using the knowledge of the local soil conditions and the relevant literature. The cotton suitable units mapped as complexes were rated by multiplying the proportion of each soil type. The sum of total area of each soil series in the unit to get respective final soil rating (AAFRD, 2004).

Soil grouping for nutrient management

The thirty two arable soil mapping units (SMU's) were grouped by cluster technique, and derived dendrogram using SPSS - windows. The regression equations as derived from soil test and crop response experimental results for cotton in the region (Gudadhe *et al.,*2011) were used to calculate fertilizer nitrogen, phosphorus and potassium to attain target cotton yield of 15 q/ha for each soil mapping unit as under

- FN (fertilizer nitrogen kg/ha)=13.1*Target yield(Q/ha)-0.75* Soil nitrogen (kg/ha)
- FP_2O_5 (fertilizer phosphorus, kg/ha)=6.83*Target yield(Q/ha)-2.84*soil phosphorus (kg/ha)
- FK_2O (fertilizer Potassium, kg/ha) =8.57*target yield(Q/ha) – 0.18 soil potassium (kg/ha)

Results and discussion

Crop concentration and combinations

The concentration and combination of crop analysis collectively in an area is quantified with the help of location quotient (LQ). The location quotient values indicate regional concentration of crops and associated crops. The high concentration of rice is observed in Jhari Jamni (3.29), maize in Ner (8.15), Kelapar (5.41) and moderately high concentration of sorghum in Kalamb (1.06), Darwha (1.37), Digras (1.08), Pusad (1.34), Mahagaon , Ghatanji (1.1) and Kelapar (1.24). Low cotton and pigeon pea concentration is recorded in Umarkhed and Pusad. High concentration of peanut and sesamum is in Pusad (2.07 Ic (index of concentration) for groundnut, 3.49 Ic for sesamum). The crop combinations are derived with Ic values > 0.75. Based on crop combinations, the district is divided broadly into five crop zones viz. i) cotton + maize + wheat in Digras, Yavatmal tehsils, (ii) cotton + sorghum + pigeon pea + in Kalamb, whereas groundnut in place of pigeon pea in Darwha, Mahagaon, (iii) cotton + bajra + sorghum + maize + pigeon pea in Ner, Arni, Kelapar, (iv) cotton + pigeon pea + sesamum in Babulgaon, Ralaegaon, Maraegaon, Jhari Jamni and (v) cotton + rice + wheat + sorghum + maize + pigeon pea in Pusad, Umarkhed and Wani tehsils (Table 1).

Land forms and soils

Thirteen landforms were identified in basaltic and sedimentary formations of Yavatmal district. Broadly, hills and ridges cover 12.6 per cent of total area in northern and central parts of Yavatmal whereas plateaus (upper, middle and lower) cover 398240 ha (29.3 per cent) in association with isolated hills, mesas and butte, and escarpments (17.7 per cent), pediplains (28.8 per cent) and plains (8.1 per cent) in south western parts of the district. Similar types of landforms were reported in basaltic terrain of Central India (Reddy *et al.*, 2002).

The hills and ridges have very shallow, well drained Gahuli and shallow Lakhi series

Table1 - Crop concentration and combinations.

Tehsil	Rice	Wheat	Bajra	Jowar	Maize	Gram	Redgram	Cotton	Ground nut	Sesamum
Ner	0.16	0.58	1.82	0.79	8.15	0.22	1.05	1.12	0.09	0.72
Babulgaon	0.16	0.51	0.61	0.91	-	0.24	1.75	1.11	0.16	0.8
Kalamb	0.39	0.55	0.32	1.06	-	0.45	1.39	1.09	0.13	0.81
Yavatmal	0.28	1.11	0.95	0.96	1.03	0.57	0.90	1.00	2.46	0.26
Darwha	0.31	0.76	0.09	1.37	-	0.35	0.68	1.02	1.86	0.02
Digras	-	1.20	1.27	1.08	1.56	0.63	1.07	0.96	0.16	0.48
Pusad	1.47	1.74	0.86	1.34	0.41	0.16	0.72	0.76	2.07	3.49
Umarkhed	2.90	1.99	0.48	0.66	-	5.73	0.45	0.59	0.33	0.97
Mahagaon	0.58	0.68	0.83	1.10	-	0.11	0.70	1.00	1.75	0.64
Arni	0.24	0.67	6.95	0.95	-	0.62	1.05	0.96	2.12	0.76
Ghatanji	2.04	0.47	0.21	1.12	0.42	0.18	0.31	1.28	1.31	0.27
Kelapur	0.53	0.89	1.05	1.24	5.41	0.16	1.44	1.00	0.16	0.94
Ralaegaon	0.47	0.87	0.28	0.94	0.30	2.03	1.53	1.05	0.02	0.59
Maregaon	0.47	0.82	0.02	0.95	-	0.50	1.77	1.08	0.09	1.13
JhariJamni	3.29	0.85	-	0.69	-	0.25	0.63	1.15	2.10	0.18
Wani	1.70	1.51	-	0.72	-	1.38	1.21	1.11	0.44	3.41

having dark grey to brown matrix with 10YR hue and clay texture throughout profiles inherited from basalts (Table 2). The upper plateaus (above 500m) in Yavatmal and Darwha regions have moderately deep Hirdi series with dark brown matrix and distinct slickensides with in one meter. The flat plateau summits have sparsely covered with teak forest but in few places, cultivation of cotton is observed. The middle plateaus (320m to 460m) in central and western parts of Yavatmal and Darwha have moderate slopes, and erosion with dominant soil series of shallow Jamwadi with hard cambic horizons , very deep Kalmab with moderately alkaline slickesided sub soils, and moderately deep Katherwadi series with sodic, strongly alkaline slickensided zones. The lower plateaus (below 320m)have moderate slopes, and sparse forest cover with moderately deep and well drained Kolambi series (very dark grey, moderately alkaline cambic horizons). The Korta and Ralaegaon soils on isolated hills have dark brown to black subsurface layers with 7.5 hue and 10YR hue, clay textured, moderately alkaline with strong and prominent slickensided zones. The mesas and butte of basaltic landforms and steep escarpments have very shallow, well drained Moho series and moderately deep Waghari series. The Moho soils have 7.5YR with dark brown matrix and thin ochric layer whereas Waghari soils have 10YR hue with dark grey matrix, moderately alkaline clay subsoils, and cambic horizons. The upper and lower pediplains are mostly cultivated for cotton during rainy season, and are mostly having deep to moderately deep shrink-swell soils of Apti, Borgaon, Dhanora, Kharbhi, Saykheda and Selodi series. These soils have dark greyish brown to dark brown matrix

Table 2 - Landforms and soils with selected morphological properties.

Land forms	Area (ha)	Area (%)	Soil series	Matrix colour (moist)* A horizon	Matrix colour (moist)* B horizon	Other features
Hills and ridges	170970	12.6	Gahuli	10YR3/3	-	Very thin ochric horizons with lithic contact below 50cm
			Lakhi	10YR3/3	-	Moderately alkaline, dark brown ochric horizons
Upper plateaus	64712	4.8	Hirdi	7.5YR3/2	7.5YR3/2	Slickensides within 1m with neutral reaction
Middle plateaus	236055	17.4	Jamwadi	10YR3/2	10YR3/1	Mildly alkaline thin and hard cambic horizons
			Kalamb	10YR4/2	10YR3/2	Moderately alkaline slicken sided zone
			Katherwadi	10YR3/2	10YR3/2	Strongly alkaline sodic slicken sided zones within 1m
Lower plateaus	97472	7.2	Kolambi	10YR3/1	10YR3/2	Moderately alkaline cambic horizons
Isolated hills	92440	6.8	Korta	7.5YR3/1	7.5YR3/1	Slightly alkaline, very hard cambic horizons
			Ralegoan	10YR3/2	10YR3/2	Moderately alkaline slicken sided zones within 50cm
Mesa and Butte	85696	6.3	Moho	7.5YR3/2	-	Neutral, thin, ochric layer
			Waghari	10YR3/2	10YR3/2	Moderately alkaline with pressure faces in cambic horizons
Escarpments	62716	4.6	Met	5YR3/2	-	Moderately alkaline, lithic contact within 50cm
Upper pediplains	175599	12.9	Borgoan	2.5Y5/2	2.5Y3/1	High value, clay increase, low chroma
			Dhanora ,	10YR3/2	10YR3/2	Thin cambic horizon
			Kharbi	10YR3/2	10YR3/1	Moderately alkaline, slicken sided zones
Lower pediplains	214729	15.8	Apti	10YR4/2	10YR3/2	Pressure faces and slicken sides within 1m
			Saykheda	10YR3/3	10YR3/4	Moderately alkaline slicken sided zones
			Selodi	10YR4/2	10YR3/2	Strongly alkaline, slicken sided zones, strongly effervescent
Gently to moderately sloping plains	45827	3.4	Arni	10YR3/2	10YR3/2	Cambic with pressure faces and slickensides
			Chikhalgoan	10YR4/2	10YR3/2	Pressure faces and slicken sides within 1m
			Penganga	10YR3/2	10YR3/2	Moderately alkaline, slicken sided zones within 1m
Very gently to gently sloping alluvial plains	15659	1.2	Arunavati	10YR4/3	10YR5/4	Gravelly Calcium carbonate enriched
			Chanoda	10YR4/2	10YR3/1	Cambic/slickensided zone with low chroma
			Loni	10YR5/4	10YR4/4	Moderately alkaline, thick slickensided zone up to 150cm
			Pandhurna	10YR4/3	10YR3/3	Moderately alkaline with coarse angular aggregates
			Wani	10YR3/2	10YR3/1	Moderately alkaline with slickensided zones
Intervening valleys	47864	3.5	Dhanki	10YR3/2	10YR3/3	Moderately alkaline, slicken sided zones
			Nagdhari	10YR6/4	10YR3/4	Moderately alkaline, sodic, prismatic aggregates
			Wanodi	10YR3/2	10YR3/2	Moderately alkaline with slicken sided zones
			Sindola	10YR3/2	10YR3/1	Moderately alkaline, cambic horizons
Gullied and Stony gravelly waste lands	47253	3.2	Maregaon	10YR3/2	10YR3/2	Moderately alkaline cambic horizons
			Pandharkawada	10YR4/3	-	Neutral brown ochric horizons
			Wanjari	10YR3/6	10YR3/4	Mildly alkaline, developed over limestone

with slickensided zone within one metre in Apti and Saykheda but in deep layers with moderately to strongly alkaline in case of Selodi. The gently to very gently sloping alluvial plains in Penganga and Pus valleys have deep Arunavati, very deep Chanoda, Loni, Pandhurna and Wani soils. These soils have very dark greyish brown to dark greyish brown, calcium carbonate enriched B horizons in Arunavati series, moderately alkaline clayey slickensided zones in other soils with deep surface cracks extending to a depth of 1 m. The intervening valleys in Penganga plains have Dhanki, Sindola, Wanodi and Nagdhari soils. These soils are very dark greyish brown to dark greyish brown/light yellowish brown, moderately to strongly alkaline, and presence of moderate medium sub - angular to angular blocky aggregates with slickensides in subsoil horizons to prismatic structures in Nagdhari series. The gullied and stony gravelly waste unit has shallow to very shallow Maregaon, Pandharkawada and Wanjari series. These soils have dark yellowish brown (Wanjari) to brown (Pandharkawada) and very dark greyish brown (Maregaon) with mildly to moderately alkaline, and clay textured cambic horizons. The very fine particle size (clay >60%) is recorded in the profiles of Dhanki, Chanoda, Painganga, Apti, Hirdi and Lakhi series.

Physical characteristics of soils

The profile distribution of sand, silt and clay in thirty three soil series of Yavatmal district shows more clay, silt contents than sand contents (Table 3). The clay less than 35 per cent is recorded in Nagdhari, Waghari series with silt of 25 to 40 per cent whereas Loni and Saykheda series, the silt content is more than 40 per cent. The sixteen series (Borgaon, Chikhalgaon, Dhanki, Gahuli, Jamwadi, Kalamb, Katherwadi, Kharbi, Met, Maregaon, Moho, Pandhurna, Selodi, Wanodi, Wani and Wanjari) have clay content of 35 to 60 per cent and silt content less than 40 per cent whereas in five series viz. Arni, Dhanora, Kolambi, Ralaegaon and Sindola have silt content more than 40 per cent in soil control section(25 to 100 cm). More than 60% of clay is recorded in six soil series (Apti, Chanoda, Dhanki, Hirdi, Lakhi and Penganga),and silt content of 25 to 40 per cent. These expansive clay soils have bulk density of 1.57 to 1.79 Mg m^{-3} and COLE value of 0.1 to 0.2 indicating very severe shrink- swell hazards (Schafer and Singer,1976). The high COLE values indicate dominance of montmorillonite controlling the degree of shrinkage (Franzmeier and Ross, 1968). The COLE value has positive linear power relationship with fine clay and clay (significant at 5% level) and its relationship is expressed in a regression equation as :

(i) $COLE = 0.076\ (\text{fine clay})^{0.279}\ (r = 0.43^{*})$

(ii) $COLE = 0.038\ (\text{clay})^{0.402}\ (r = 0.46^{*})$

Similar kind of relation of COLE with clay were reported in shrink-swell soils of river Niger in eastern Nigeria (Igwe, 2003).

The water retention at 33 and 1500kPa on top soil horizons seem to be higher than the subsoil horizons. This may be due to combined retention capabilities of clay and organic carbon on top soil horizons. However, as the clay content increases, the water retention also increases within the profile. These soils have 12.65 per cent of mean plant available water (difference between water held at 33 kPa and 1500kPa) with standard deviation of 2.95 per cent and available water showing negative relation with $CaCO_3$ content (r = -0.41*, significant at 1% level). The clay and fine clay has a significant positive relation with water held at -33kPa and -1500 kPa. The plant available water can be approximated with multiple regression equation having R^2 value (coefficient of determination) of 0.29 and F value of 2.25.

Plant available water (%) = - 6.39 + 0.156 (sand) + 0.283 (silt %) + 0.189 (clay %) – 0.433 (organic carbon g/kg) – 0.022 (calcium carbonate, g/kg)

Chemical properties of soils

The soils are grouped into 4 reaction classes such as (i) neutral (3 series Hirdi, Met, Moho), (ii) mildly alkaline (4 series, Jamwadi, Pandharkawada, Sindola and Wanjari), (iii) moderately alkaline (21 series, Arunavati, Arni, Chikhalgaon, Dhanora, Dhanki, Gahuli, Kolambi, Kalamb, Korta, Kharbi, Loni, Lakhi, Maregaon, Nagdhari, Pandhurna, Penganga, Ralaegaon, Saykheda, Waghari, Wanodi and Wani) and (iv) strongly alkaline (4 series, Apti, Borgaon, Katherwadi, Selodi). In general, soil reaction increases from top soil to subsoil horizons in Arunavati, Arni, Apti, Borgaon, Chikhalgaon, Katherwadi, Loni and Selodi series with low salt concentrations (EC from 0.08 to 0.5 dS m^{-1}, Table 4).

Sixty seven per cent of soils (24 soil series) are low in organic carbon (less than 0.5) and remaining thirty three per cent are medium in organic carbon status (0.5 to 0.75%). The organic carbon decreases with depth except in Chikhalgaon and Loni, Wanjari where organic carbon is irregular with depth. The depth wise distribution of calcium carbonate shows increasing trends in Arunavati (72 to 177.5 g/kg), Saykheda (61.2 to 196.8 g/kg), Waghari (50 to 124 g/kg), and Wani (44 to 95 g/kg). The calcium carbonate content less than one g/kg is observed in Dhanki series whereas as less than 6 g/kg in case of Chanoda, Jamwadi, Kolambi, Katherwadi, Korta, Kharbi, Loni, Moho, Nagdhari, Penganga, Ralaegaon, Sindola, and other soils the $CaCO_3$ content is in between 5 to 10g/kg. Among exchangeable bases Ca is dominated over Mg, Na and K. The weighted means for exchangeable Ca vary from 25.3 cmol/kg (Moho series, P20) to 61.58 cmol/kg (Wani series, P30). The increasing depth trends of calcium is clearly observed in Kalamb (43 to 70 cmol/kg), Korta (43 to 55 cmol/kg), Maregaon (51 to 53 cmol/kg), Waghari (54 to 71 cmol/kg)and Wani (51 to 71 cmol/kg). These soils have high exchangeable Mg (0.5 meq/100g, MAFF, 1986) with mean of 6.92 cmol/kg (Dhanora, P7) to 19.93 cmol/kg (Katherwadi series, P14). The magnesium percentage is more than 30 per cent in Arunavati, Arni, Apti, Chikhalgaon, Hirdi, Katherwadi, and Maregaon series. The ExCa to ExMg ratio > 5:1 in Borgaon, Dhanora, Saykheda, Waghari and Wani series. The exchangeable Na contents are generally low but exceeding >15 per cent and shows increasing trend within Arni and Katherwadi series. The exchangeable K contents is in adequate amounts (0.4 to 0.8 cmol(p+) kg^{-1}) but

Table 3 - Physical characteristics of soils.

Soil series	Depth (cm)	Horizon	Particle size(%)(<2mm)				Textural class	Fineclay/ Total clay X100	Bulk density (Mgm^{3})	COLE	Water retention (%)	
			Sand	Silt	clay	Fine clay					-33 kPa	-1500 kPa
Arunavati	0-19	Ap	36.9	35.9	27.2	9.7	l	35.1	1.58	0.12	49.9	10.4
	19-55	Bk1	30.7	42.7	26.6	11.3	l	42.5	1.60	0.10	21.9	11.1
	55-95	Bk2	71.3	22.2	6.5	4.6	Sl	70.7	1.56	0.10	11.9	7.1
Arni	0-18	Ap	18.3	49.7	32.0	13.9	ZCl	43.5	1.63	0.18	34.3	16.0
	18-37	Bw	12.3	46.9	41.2	12.3	ZCl	29.8	1.64	0.20	34.1	16.8
	37-63	Bss1	12.1	47.1	40.8	11.9	ZC	29.2	1.91	0.22	33.7	16.5
	-63-94	Bss2	9.6	54.1	36.3	12.8	ZCl	35.3	1.87	0.26	46.9	20.7
Apti	0-13	Ap	4.1	34.7	61.2	27.5	C	44.9	1.67	0.17	28.1	16.2
	13-33	Bw	3.8	35.0	61.2	31.6	C	51.6	1.61	0.17	26.7	17.4
	33-70	Bss1	2.6	26.1	71.3	30.5	C	42.8	1.83	0.22	27.2	17.4
Borgaon	0-16	Ap	7.0	43.5	49.5	16.8	ZC	33.9	1.48	0.24	25.6	14.6
	16-35	Bw1	4.8	44.5	50.7	27.3	ZC	53.9	1.63	0.21	29.9	18.7
	35-54	Bw2	11.6	33.2	55.2	16.9	C	30.7	1.63	0.19	27.7	17.3
	54-67	BC	29.4	36.4	34.2	9.6	Cl	28.1	1.76	0.13	19.9	11.9
Chikhalgaon	0-13	Ap	21.9	41.7	36.4	16.2	Cl	44.4	1.71	0.18	29.1	14.9
	13-41	Bw	18.2	40.72	41.1	22.3	ZC	54.3	1.79	0.17	26.2	15.0
	41-74	Bss1	14.5	42.45	43.1	27.2	ZC	63.2	1.80	0.17	36.4	17.5
	74-95	Bss2	12.3	50.09	37.7	22.1	ZC	58.6	1.85	0.17	27.7	17.6
Chanoda	0-13	Ap	5.0	45.9	49.1	22.4	ZC	45.7	1.69	0.19	34.5	20.0
	13-28	Bw	4.0	34.0	62.1	34.0	C	54.8	1.87	0.21	41.7	21.4
	28-60	Bss1	2.9	18.7	78.5	38.7	C	49.3	1.74	0.23	41.3	22.3
	60-98	Bss2	2.0	33.7	64.4	37.0	C	57.5	1.81	0.20	43.4	25.0
	98-150	Bss3	2.5	25.4	72.2	39.4	C	54.7	1.91	0.23	28.2	17.3
Dhanora	0-13	Ap	5.6	39.5	54.9	15.1	C	27.5	1.74	0.19	29.4	18.1
	13-30	Bw	6.5	42.7	50.8	17.8	ZC	35.1	1.65	0.20	25.7	16.6
Dhanki	0-15	Ap	1.3	32.2	66.4	46.0	C	69.3	1.71	0.23	29.7	15.4
	15-40	Bw	1.1	35.3	63.6	41.9	C	65.9	1.68	0.23	26.0	16.9
	40-75	Bss1	1.2	34.6	64.0	44.5	C	69.6	1.75	0.22	28.2	15.9
	75-115	Bss2	1.5	37.8	60.7	54.3	C	89.5	1.77	0.23	31.2	18.6
	115-170	Bss3	1.2	31.7	67.1	58.4	C	87.0	1.67	0.22	30.0	18.3
Gahuli	0-17	Ap	10.1	39.5	50.4	12.3	C	24.4	1.48	0.15	23.7	12.6
Hirdi	0-12	Ap	3.8	39.0	57.2	26.5	C	46.2	1.56	0.18	30.1	15.1
	12-32	Bw	2.3	29.8	67.9	51.2	C	75.6	1.72	0.19	31.0	17.4
	32—75	Bss	2.3	228.0	69.7	52.8	C	75.1	1.74	0.18	34.7	18.2
Jamwadi	0-20	Ap	11.3	45.2	43.5	25.5	C	58.5	1.80	0.21	24.7	15.4
	20-40	Bw1	14.8	31.2	54.0	34.8	C	64.4	1.78	0.20	25.8	13.3
Kalamb	0-20	Ap	1.7	40.3	58.0	25.6	C	44.1	1.51	0.17	34.6	19.3
	20-41	Bw	1.5	37.9	60.6	22.8	C	37.6	1.49	0.20	35.9	18.9
	41-70	Bss1	1.9	34.2	63.9	30.3	C	46.7	1.61	0.20	33.8	21.5
	70-96	Bss2	1.7	36.7	63.6	33.0	C	52.7	1.72	0.18	34.3	20.9
	96-114	Bss3	1.4	28.0	70.6	20.9	C	29.2	1.69	0.17	36.0	17.3
	114-160	Ck	8.76	55.4	35.8	21.4	C	59.8	1.71	0.18	32.5	18.2
Kolambi	0-20	Ap	4.8	36.6	58.5	28.4	C	48.5	1.70	0.23	26.2	17.1
	20-47	Bw1	6.4	37.4	56.2	32.4	C	57.6	1.79	0.24	26.9	17.2
	47-89	Bw2	31.0	31.2	37.1	13.1	C	56.5	1.62	0.18	28.3	16.5
Katherwadi	0-12	Ap	13.7	35.4	50.9	22.8	C	44.9	1.52	0.21	35.4	19.0
	12-28	Bw1	11.9	32.9	55.2	26.3	C	47.5	1.73	0.20	38.8	17.3
	28-49	Bw2	11.7	33.6	54.7	28.6	C	52.2	1.80	0.20	37.2	21.6
	49-72	Bss1	10.2	32.6	57.2	30.7	C	53.7	1.78	0.19	36.9	21.9
	72-96	Bss2	11.7	37.3	51.0	21.7	C	42.5	1.76	0.20	35.6	18.1
Korta	0-20	Ap	21.1	26.0	53.8	29.2	C	55.7	1.82	0.24	29.7	20.2
	20-50	Bw	24.1	22.8	53.1	28.4	C	53.3	1.77	0.24	31.7	21.3
Kharbi	0-20	Ap	4.3	39.6	56.1	21.2	C	37.8	1.76	0.20	33.5	20.0
	20-50	Bw	3.8	35.6	60.6	33.9	C	55.9	1.63	0.21	37.5	20.0
	50-70	Bss1	2.9	33.5	63.6	42.2	C	66.3	1.89	0.22	29.1	18.4
	70-100	Bss2	19.5	24.1	56.4	42.5	C	74.8	1.75	0.22	35.6	15.5
	100-130	Bss3	23.0	20.2	58.8	26.5	C	45.1	1.71	0.22	33.0	16.2
Loni	0-15	Ap	16.7	45.3	38.0	10.8	ZCl	28.0	1.51	0.17	37.3	19.7
	15-40	Bw1	13.0	57.2	35.8	14.6	ZCl	40.7	1.60	0.20	37.3	21.6
	40-74	Bss12	13.4	49.2	37.4	13.7	ZCl	36.7	1.71	0.20	38.9	21.8
	74-106	Bss2	13.9	53.0	33.1	14.1	ZCl	42.5	1.73	0.22	38.3	20.7
	106-150	Bss3	12.9	52.8	34.3	14.7	ZCl	42.6	1.74	0.18	38.9	20.7

Table 3 - continued

Soil series	Depth (cm)	Horizon	Particle size(%)(<2mm)				Textural class	Fineclay/ Total clay X100	Bulk density (Mgm³)	COLE	Water retention (%)	
			Sand	Silt	clay	Fine clay					-33 kPa	-1500 kPa
Lakhi	0-26	Ap	5.4	27.6	67.0	33.1	C	49.4	1.70	0.20	25.2	13.6
Met	0-20	Ap	20.4	33.1	46.5	32.2	C	69.2	1.65	0.18	31.1	19.3
	20-40	Cr	63.4	25.0	11.6	6.4	Sl	55.2	1.74	0.07	15.6	7.6
Moho	0-7	A	34.2	28.8	37.0	20.7	Cl	56.1	1.60	0.14	27.0	17.6
	7-23	AC	46.3	30.1	23.6	14.2	l	64.0	1.55	0.19	30.4	17.9
Maregaon	0-15	Ap	8.2	33.6	58.2	24.4	C	41.9	1.66	0.19	33.3	21.2
	15-42	Bw	7.0	33.0	60.0	31.6	C	52.7	1.73	0.20	39.2	21.0
Nagdhari	0-18	Ap	18.9	45.9	35.2	13.5	ZCl	38.3	1.67	0.16	25.5	15.6
	18-43	Bw1	18.6	46.7	34.7	12.7	ZCl	47.3	1.52	0.16	28.1	19.6
	43-64	Bw2	17.8	51.4	30.8	13.3	ZCl	43.3	1.62	0.16	31.0	20.9
	64-85	Bw3	18.9	53.3	27.8	10.6	ZCl	37.9	1.78	0.16	31.7	20.5
	85-110	Bw4	15.5	57.0	27.5	12.1	ZCl	44.0	1.53	0.15	32.0	17.1
	110-140	Bw5	10.2	57.4	32.4	14.2	ZCl	43.7	1.70	0.15	32.1	17.6
Pandhurna	0-13	Ap	40.6	36.4	23.0	17.1	l	75.6	1.55	0.11	26.6	17.4
	13-38	Bw1	31.2	36.5	32.3	18.9	Cl	58.5	1.48	0.18	31.6	16.6
	38-62	Bw2	31.5	35.2	33.3	26.4	Cl	79.2	1.50	0.19	31.9	18.8
	62-87	Bw3	38.1	28.8	33.1	15.5	Cl	46.9	1.67	0.22	29.7	17.9
	87-150	Bw4	15.1	32.6	52.2	34.2	C	65.6	1.60	0.28	31.8	17.0
Pandharkawada	0-11	Ap	29.5	18.1	52.5	19.1	C	36.4	1.52	0.15	23.6	11.9
Penganga	0-15	Ap	2.0	54.4	43.6	21.4	SiC	49.1	1.77	0.21	29.7	18.3
	15-50	Bw	1.6	31.6	66.8	32.2	C	48.2	1.87	0.20	32.1	21.1
	50-85	Bss1	1.2	28.6	70.2	42.6	C	60.7	1.73	0.22	32.3	21.1
Ralaegaon	0-15	Ap	9.3	46.1	44.6	14.3	ZC	31.9	1.76	0.18	27.6	17.6
	15-42	Bw	9.7	46.3	44.0	14.4	ZC	32.6	1.72	0.18	31.3	17.5
	42-70	Bss1	5.6	41.7	52.7	23.3	ZC	44.5	1.72	0.17	32.0	18.9
	70-96	BC	19.9	45.7	34.4	13.3	ZC	38.6	1.58	0.14	32.6	20.5
Saykhed	0-19	Ap	8.0	50.1	41.9	15.0	ZC	35.9	1.78	0.20	30.4	18.1
	19-47	Bw	7.9	48.5	43.6	21.1	ZC	48.5	1.61	0.21	30.9	19.5
	47-82	Bss1	9.8	51.9	38.2	18.0	ZC	47.2	1.52	0.20	28.0	18.1
	82-118	Bss2	15.1	31.6	53.3	9.5	Sl	62.9	1.52	0.084	16.3	9.5
	118-150	Bss3	14.6	35.9	49.5	8.6	l	59.1	1.56	0.085	13.5	9.1
Selodi	0-12	Ap	5.8	44.4	49.8	17.5	ZC	35.2	1.50	0.24	30.0	18.2
	12-38	Bw1	5.6	41.3	50.2	21.7	ZC	43.3	1.50	0.23	34.6	17.6
	38-71	Bss1	5.0	35.4	59.6	26.1	C	43.8	1.90	0.22	33.2	18.8
	71-103	Bss2	4.5	35.2	60.3	27.5	C	45.6	1.89	0.19	28.5	14.5
	103-150	Bss3	2.6	30.4	67.0	32.6	C	48.6	1.83	0.16	32.1	17.1
Sindola	0-12	Ap	6.6	43.4	45.0	33.8	ZCl	75.2	1.70	0.16	30.7	15.2
	12-25	Bw1	6.2	40.4	53.4	26.6	ZC	50.3	1.78	0.16	34.4	17.4
	25-52	Bw2	5.2	40.4	56.4	30.4	ZC	53.9		0.17	36.7	21.0
Waghari	0-19	Ap	19.0	39.7	41.3	20.1	C	48.8	1.62	0.23	27.8	18.6
	19-48	Bw	33.3	34.2	32.5	18.0	Cl	55.3	1.61	0.16	23.1	14.9
Wanodi	0-15	Ap	7.8	38.0	54.2	17.0	C	31.3	1.60	0.20	29.4	16.3
	15-42	Bw	3.6	37.0	59.4	25.0	C	45.1	1.65	0.23	30.1	19.3
	42-72	Bss1	3.2	38.3	58.6	22.8	C	38.9	1.70	0.195	32.8	20.1
	72-98	Bss2	3.9	37.8	58.3	23.0	C	39.5	1.69	0.23	31.8	19.1
	98-152	Bss3	4.5	38.1	57.4	23.3	ZC	39.1	1.70	0.18	32.3	20.3
Wani	0-12	Ap	17.2	38.7	44.1	20.7	C	46.8	1.73	0.19	32.3	20.3
	12-42	Bw	17.3	34.2	48.5	22.5	C	46.4	1.75	0.19	32.9	19.8
	42-70	Bss1	17.3	33.9	49.8	24.1	C	49.4	1.66	0.22	34.0	16.9
	70-101	Bss2	19.7	31.8	48.5	24.8	C	51.1	1.70	0.22	31.3	17.2
	101-140	Bss3	20.8	29.7	49.5	27.3	C	58.7	1.68	0.22	34.9	16.6
Wanjari	0-13	Ap	8.5	35.9	55.6	18.7	C	33.6	1.62	0.14	22.8	15.3
	13-40	Bw1	9.5	39.3	51.2	17.6	ZC	36.2	1.52	0.17	24.5	17.5

maintenance of K usually desirable. This is in conformity with more than 2% K saturation as suggested minimum level to avoid K deficiency. These shrink-swell soils have very high CEC (>40 cmol (+) kg^{-1}) with CEC to clay ratio of 80 to 100 indicating dominance of montmorillonitic and adequate reserves of Mg and K.

Table 4 - Chemical characteristics of soils.

Soil series	Depth (cm)	Horizon	pH	EC	OC g/kg	$CaCO_3$ (g/kg)	Extractable bases (cmol/kg)				CEC
							Ca	Mg	K	Na	(cmol/kg)
1. Arunavati	0-19	Ap	8.4	0.17	7.4	72.8	28.7	10.4	0.21	0.58	41.7
	19-55	Bk1	8.5	0.15	4.0	95.5	24.1	14.0	0.23	0.13	43.5
	55-95	Bk2	8.6	0.14	2.2	177.5	23.3	15.6	0.48	0.09	31.3
2. Arni	0-18	Ap	8.0	0.13	6.0	5.6	73.50	12.18	0.36	1.07	58.3
	18-37	Bw	8.1	0.21	4.5	8.3	48.79	18.26	3.06	0.63	56.5
	37-63	Bss1	9.0	0.25	3.4	7.8	46.71	19.58	5.23	0.53	45.9
	63-94	Bss2	9.3	0.58	2.6	10.8	30.58	22.73	11.85	0.51	49.0
3. Apti	0-13	Ap	8.5	0.13	3.5	150.2	42.43	11.12	0.84	0.69	48.7
	13-33	Bw	8.9	0.16	2.9	160.4	43.43	12.87	1.34	0.49	47.8
	33-70	Bss1	8.8	0.37	2.6	135.8	44.93	19.8	1.49	0.45	57.4
4. Borgaon	0-16	Ap	8.3	0.23	7.3	152.2	68.88	7.42	0.10	1.27	70.4
	16-35	Bw1	8.3	0.21	5.8	25.3	72.62	10.20	0.15	0.47	57.4
	35-54	Bw2	8.5	0.19	4.4	84.8	71.82	13.76	0.14	0.71	43.5
	54-67	Bw3	8.6	0.17	2.3	9.47	67.11	14.89	0.13	0.24	46.1
5. Chikhalgaon	0-13	Ap	8.1	0.17	6.0	56.5	37.52	16.33	0.66	0.69	37.4
	13-41	Bw	8.3	0.17	3.6	70.2	31.41	14.19	0.93	0.43	40.9
	41-74	Bss1	8.6	0.29	2.7	69.3	39.81	10.89	0.74	0.48	41.7
	74-95	Bss2	8.8	0.39	1.9	59.6	28.49	13.52	0.66	0.49	40.0
6. Chanoda	0-13	Ap	8.0	0.26	2.6	30.2	52.74	8.25	0.52	0.73	62.6
	13-28	Bw1	8.1	0.11	1.1	32.1	50.27	7.92	0.45	0.58	66.1
	28-60	Bw2	8.2	0.16	1.6	43.2	63.27	9.90	0.49	0.58	70.4
	60-98	Bss1	8.2	0.12	1.2	62.1	63.45	13.36	0.51	0.62	66.1
	98-150	Bss2	8.1	0.11	1.1	27.1	59.28	23.10	0.51	0.55	66.9
7. Dhanora	0-13	Ap	8.0	0.23	11.1	33.7	45.88	7.57	0.16	0.93	69.5
	13-30	Bw	8.2	0.18	2.9	88.1	50.81	6.43	0.17	0.82	70.4
8. Dhanki	0-15	Ap	7.8	0.09	6.3	4.5	44.85	7.93	0.15	0.55	75.7
	15-40	Bw	8.1	0.14	5.6	5.1	47.01	7.72	0.65	0.41	70.4
	40-75	Bss1	8.2	0.12	4.9	4.3	47.64	8.75	0.64	0.37	67.0
	75-115	Bss2	8.3	0.14	4.5	9.6	50.71	11.52	0.48	0.45	71.3
	115-170	Bss3	8.1	0.16	3.5	8.8	49.05	16.22	0.19	0.48	69.6
9. Gahuli	0-17	Ap	8.0	0.16	2.5	5.6	36.71	14.31	0.78	0.53	55.1
10. Hirdi	0-12	Ap	6.5	0.08	9.9	Nil	42.63	21.45	0.44	0.54	47.8
	12-32	Bw	6.7	0.11	5.3	Nil	46.02	21.78	0.40	0.44	53.9
	32-75	Bss	7.1	0.08	4.9	Nil	46.75	16.50	0.52	0.48	54.7
11. Jamwadi	0-20	Ap	7.6	0.12	7.6	40.9	41.10	14.78	0.11	0.43	70.4
	20-40	Bw1	7.5	0.17	7.2	44.6	47.82	15.07	0.19	0.35	74.8
12. Kalamb	0-20	Ap	8.01	0.22	4.7	0	47.05	11.71	0.62	0.35	62.6
	20-41	Bw	8.2	0.15	4.11	0	43.90	19.8	0.68	0.33	60.8
	41-70	Bss1	8.1	0.20	2.6	0	57.80	14.18	0.69	0.49	62.6
	70-96	Bss2	8.0	0.21	2.3	0	59.40	17.44	0.69	0.49	72.1
	96-114	Bss3	8.1	0.17	2.0	5.6	48.19	19.80	0.71	0.45	61.7
	114-160	Ck	8.3	0.20	1.7	30.0	35.48	21.45	0.68	0.43	47.8
13. Kolambi	0-20	Ap	7.8	0.20	6.8	69.3	43.63	8.97	0.12	0.86	69.1
	20-47	Bw1	8.2	0.20	5.3	67.3	60.84	7.62	0.13	0.82	67.8
	47-89	Bw2	8.3	0.16	2.2	149.3	70.14	8.31	0.19	1.32	53.9
14. Katherwadi	0-12	Ap	8.4	0.14	7.3	1.4	42.96	17.05	0.73	0.54	55.7
	12-28	Bw1	8.6	0.21	6.3	2.3	52.71	18.91	1.76	0.47	58.3
	28-49	Bw2	8.8	0.33	3.8	3.3	46.97	17.62	4.90	0.59	53.9
	49-72	Bss1	9.0	0.46	3.8	3.9	47.39	19.63	9.36	0.62	58.3
	72-96	Bss2	9.3	0.67	1.7	5.1	41.69	24.36	11.36	0.57	56.5
15. Korta	0-20	Ap	8.0	0.18	3.3	32.5	43.18	12.83	0.20	0.93	49.1
	20-50	Bw	7.8	0.28	2.6	42.0	46.32	12.14	0.19	0.84	53.9
	50-60	Cr	8.3	0.19	2.2	37.8	55.29	9.38	0.14	0.72	54.8
16. Kharbhi	0-20	Ap	7.9	0.16	4.8	Nil	49.77	7.52	0.17	1.0	58.5
	20-50	Bw	8.1	0.15	4.0	Nil	49.45	7.90	0.19	0.60	58.1
	50-70	Bss1	8.2	0.20	2.9	Nil	50.80	12.85	0.14	0.58	64.4
	70-100	Bss2	8.1	0.23	2.6	Nil	47.36	14.73	0.12	0.60	62.8
	100-130	Bss3	8.0	0.20	2.3	Nil	42.35	17.78	0.11	0.58	60.8
17. Loni	0-15	Ap	8.2	0.17	0.4	12.6	53.40	14.19	0.52	0.55	40.9
	15-40	Bw1	8.4	0.13	2.7	10.3	57.50	11.05	0.49	0.49	43.5
	40-74	Bss1	8.5	0.12	1.3	8.3	43.80	11.45	0.76	0.33	53.9
	74-106	Bss2	8.5	0.13	0.4	7.1	42.70	15.41	0.71	0.43	53.0
	106-150	Bss3	8.5	0.13	0.7	8.7	41.0	13.10	0.76	0.41	50.4

Table 4 - Continued

Soil series	Depth (cm)	Horizon	pH	EC	OC g/kg	$CaCO_3$ (g/kg)	Extractable bases (cmol/kg)				CEC
							Ca	Mg	K	Na	(cmol/kg)
18. Lakhi	0-26	Ap	8.4	0.13	2.6	16.5	44.13	15.69	1.75	1.39	67.0
19. Met	0-20	Ap	6.6	0.08	5.7	Nil	26.50	11.04	0.06	0.28	52.1
20. Moho	0-7	A	7.0	0.12	1.4	3.0	23.50	13.33	0.13	0.28	43.0
	7-23	AC	7.3	0.10	1.3	3.7	16.09	17.97	0.17	0.31	26.1
21. Maregaon	0-15	Ap	8.2	0.14	6.6	25.9	51.05	16.40	0.83	0.83	61.7
	15-42	Bw	8.1	0.11	6.6	19.7	53.46	20.85	0.95	0.81	64.3
22. Nagdhari	0-18	Ap	8.2	0.24	1.7	2.4	34.16	19.47	0.76	0.68	46.9
	18-43	Bw1	8.3	0.22	1.1	3.6	35.46	16.23	0.76	0.60	48.7
	43-64	Bw2	8.3	0.21	1.1	4.7	34.28	15.41	0.83	0.56	44.3
	64-85	Bw3	8.3	0.24	0.5	5.2	31.12	15.24	0.88	0.56	42.6
	85-110	Bw4	8.4	0.21	0.5	4.3	38.61	16.73	0.86	0.59	47.8
	110-144	Bw5	8.3	0.22	0.3	3.9	32.81	18.64	0.71	0.62	48.7
23. Pandhurna	0-13	Ap	8.1	0.11	6.9	67.8	49.14	7.34	0.16	0.28	56.5
	13-38	Bw1	8.2	0.12	5.6	77.7	55.71	7.83	0.22	0.23	58.3
	38-62	Bw2	8.2	0.14	5.2	90.7	52.09	8.70	0.17	0.28	53.9
	62-87	Bw3	8.2	0.15	4.2	112.2	56.55	8.94	0.16	0.19	52.2
	87-150	Bw4	8.3	0.25	3.8	84.9	56.85	12.57	0.20	0.32	46.1
24.Pandharkawada	0-11	Ap	7.5	0.21	1.3	4.1	33.2	12.34	0.74	1.39	62.6
25. Penganga	0-15	Ap	8.4	0.19	6.4	89.6	52.79	10.48	0.11	2.71	73.9
	15-50	Bw	8.3	0.20	3.4	91.7	50.50	17.39	0.41	0.95	72.9
	50-85	Bss1	8.3	0.22	3.0	89.3	52.23	19.88	0.53	0.92	69.6
26. Ralaegaon	0-15	Ap	8.0	0.32	6.1	1.23	42.8	13.36	0.68	0.42	57.4
	15-42	Bw	8.2	0.19	6.7	1.6	39.50	12.87	0.59	0.42	53.0
	42-70	Bss1	8.2	0.19	5.5	3.2	53.61	16.33	0.59	0.57	69.5
	70-84	BC	8.5	0.26	2.3	4.6	63.30	7.09	0.78	0.27	70.4
27. Saykhed	0-19	Ap	8.3	0.34	7.7	61.2	57.7	6.93	0.40	1.29	63.5
	19-47	Bw	8.2	0.20	6.3	72.8	69.52	6.07	0.45	0.82	58.3
	47-82	Bss1	8.6	0.14	4.4	107.2	74.68	6.09	0.39	0.44	53.9
	82-118	Bss2	8.4	0.13	3.7	142.2	56.64	4.79	0.33	0.29	41.7
	118-150	Bss3	8.5	0.13	1.8	196.8	46.73	5.09	0.29	0.31	37.4
28. Selodi	0-12	Ap	8.4	0.22	4.5	105.0	62.71	11.93	0.45	1.48	62.6
	12-38	Bw1	8.5	0.21	3.4	114.2	59.90	13.94	0.90	0.93	64.3
	38-71	Bss1	8.8	0.27	2.6	120.6	59.60	17.63	2.89	0.85	66.1
	71-103	Bss2	9.0	0.38	2.2	101.2	48.41	19.07	5.91	0.90	67.8
	103-150	Bss3	9.1	0.48	1.9	115.7	44.03	26.12	9.40	1.12	68.7
29. Sindola	0-12	Ap	8.0	0.45	7.0	1.35	49.42	14.75	0.85	0.83	53.9
	12-25	Bw1	7.3	0.12	3.2	1.54	39.10	12.04	0.66	0.64	50.4
	25-52	Bw2	7.7	0.10	3.2	1.48	39.55	9.24	0.59	0.27	53.9
30. Waghari	0-19	Ap	8.2	0.22	7.70	50.4	34.17	10.99	0.15	0.62	46.3
	19-48	Bw	8.4	0.15	6.30	123.6	49.22	11.27	0.17	0.35	64.3
31. Wanodi	0-15	Ap	8.2	0.19	6.3	1.9	43.10	12.25	0.46	0.98	57.4
	15-42	Bw	8.3	0.19	2.8	2.35	45.95	12.86	0.55	0.65	61.6
	42-72	Bss1	8.4	0.12	1.4	3.69	45.13	20.39	0.35	0.50	66.9
	72-98	Bss2	8.4	0.13	1.4	14.75	43.45	25.12	0.31	0.36	65.3
	98-154	Bss3	8.3	0.14		15.89	40.14	25.81	0.36	0.50	57.3
32. Wani	0-12	Ap	8.1	0.21	4.9	44.4	51.96	3.39	.015	0.90	58.3
	12-42	Bw	8.3	0.16	3.2	60.0	53.76	2.99	0.14	0.76	57.4
	42-70	Bss1	8.4	0.16	2.6	71.0	54.25	3.67	0.17	1.16	60.9
	70-101	Bss2	8.2	0.17	2.6	81.5	56.2	4.16	0.18	0.82	58.5
	101-140	Bss3	8.2	0.17	2.6	95.4	57.48	5.28	0.24	0.89	63.4
33. Wanjari	0-13	Ap	7.8	0.11	2.6	57.2	46.27	8.91	0.32	0.30	53.9
	13-40	Bw1	7.8	0.08	8.5	63.8	39.25	11.38	0.35	0.34	53.5

Soil Classification

Based on morphology, physical and chemical characteristics of thirty three soil series were classified in the subgroups of Entisols, Inceptisols and Vertisols as per Soil Survey Staff (2006).The soil series under each subgroup with diagnostic characteristics is presented in Table 5.

Table 5 -Classification of soils in Yavatmal district.

Sr. No.	Soil Subgroup	Soil series	Diagnostic characters	
			Surface	Subsurface
1	Lithic Ustorthents	Lakhi, Met, Pandharkawada	Ochric epipedon with hard rock	Hard rock within 25 cm depth
2	Typic Calciustepts	Arunavati, Pandhurna	Ochric epipedon	Calcic horizon is 70 cm thick or more with calcium carbonate of 7.3 to 17.8 per cent
3	Sodic Haplusterts	Katherwadi, Selodi	Ochric epipedon	Sodic pedon with exchangeable sodium percentage of 15 and more
	Aridic Leptic Haplusterts	Arni	Ochric epipedon	Haplusterts that have both a densic, lithic or paralithic contact within 100cm of the mineral surface and cracks in normal years that are 5mm or more wide through a thickness of 25 cm or more within 50cmof the mineral surface for 210 or more consecutive days per year.
4	Leptic Haplusterts	Apti, Chikhalgaon, Penganga Hirdi, Ralaegaon	Ochric epipedon	These soils have slickensided zone within 100 cm depth and paralithic contact within 100 cm
5	Typic Haplustepts	Borgaon, Korta, Moregaon, Waghari, Sindola	Ochric epipedon	The cambic horizon 15 cm or more thick
6	Typic Haplusterts	Chanoda Kharbi, Saykheda Wanoda, Wani, Dhanki , Kalamb	Ochric epipedon	Slickensided zone occurred within 60 cm depth with angular blocky structure
7	Lithic Haplustepts	Dhanora, Jamwadi, Wanjari	Ochric epipedon	Lithic contact within 50 cm depth
8	Typic Ustorthents	Gahuli, Moho	Ochric epipedon	Paralithic contact after 50 cm depth
9	Vertic Haplustepts	Kolambi, Nagdhari	Ochric epipedon	On vertic properties with 2 cm wide cracks upto 50 cm depth or more with wedge-shape aggregates
10	Chromic Haplusterts	Loni	Ochric epipedon	These soils having chroma of 4 or more
11	Calcic Haplusterts	Kalamb	Ochric epipedon	The soils have calcic horizon within 150 cm

Seasonal factors influencing soil water dynamics

The climate in Yavatmal district is hot semi-arid eco-region with four seasons such as hot season (March and extends up to the first week of June), south west monsoon season (June 2nd week to till the1st week of September), post monsoon season (2nd week of September to 1st week of December), and cold season (2nd week of December to till February) with the mean daily minimum temperature of 13^{0}C. The cold waves over northern India sometimes affect the district, and the minimum temperature may

Table 6 - Decadal variations in temperature and precipitation in Yavatmal district.

Month	Maximum air Temparature (°C)				Precipitation (mm)			
	1971-1980	1981-1990	1991-2000	2001-2005	1971-1980	1981-1990	1991-2000	2001-2005
January	28.7	28.7	28.4	28.2	5.8	16.4	0	33.8
February	31.7	31.9	31.2	31.8	11.3	16.4	24.7	6.3
March	36.5	35.7	36.0	36.2	10.4	9.8	0	5.5
April	40.5	40.3	39.8	39.6	10.5	2.7	0	11.3
May	41.9	41.5	41.3	41.1	21.4	16.9	71.2	17.4
June	36.5	36.4	36.2	35.7	169.0	227.5	276.5	263.8
July	30.8	30.8	30.4	31.1	247.8	261.8	482.0	285.3
August	29.1	29.1	29.2	28.1	327.8	291.7	167.1	329.3
September	31.2	31.3	30.5	30.9	121.3	157.8	53.0	82.1
October	31.7	31.4	31.2	30.7	57.6	79.0	13.6	96.5
November	30.1	29.7	29.3	30.1	27.4	9.7	0	0.3
December	28.5	28.1	27.9	28.7	13.9	17.5	0	2.8
Seasonality index(SI)					1.02	0.74	1.03	1.05
Precipitation regime					Most precipitation in <3 months	Seasonal	Most precipitation in <3	
Precipitation concentration index (PCI)					20.71 High concentration	19.4 Irregular distribution	29.2 Very high concentration	21.53

drop to 5⁰C. It was reported that the monsoon sowing, 24th to 25th meteorological week was optimum period for cotton in the region. The water balance diagram of Yavatmal (Figure 2) shows that the black soils in the region are saturated with water and kept close to field capacity due to the 70 to 80 per cent of monsoon rainfall concentrated from June to August. It was observed during field surveys of this region and also analysed thirty five years of climatic data that soil water recovers from short dry spells generally with the receival of rains, and restore excess water in the top soil. The long term rainfall pattern in Yavatmal region(1971 to 2005) has mean of 1088.5 mm ± 46.87 mm with coefficient of variation of 4.4 per cent. In general, the region receives 85 per cent of (935 mm) total rainfall during June to September (Table 6). The total rainfall varies from 1024.2mm (1971-1980) to 1134.2mm (2001-2005) with an increase of 4.2 per cent over mean, and less than 50 per cent variation. The seasonality index based on rainfall pattern was worked out to characterize precipitation regime as seasonal during the period of 1981 to 1990 but most precipitation is in < 3 months in the rest of the period. This observation is in agreement with the findings of Guhathakur and Saji (2013) reporting the seasonality index more than 1 for this region of Maharashtra. These results are further confirmed from the calculation of precipitation concentration index values (PCI) varying from 19.4 (1981-1990) with irregular distribution to 20.71 with high concentration and > 21 with very high concentration.

The dry stage is often with at least 15 days of dry spells after September 15th in the region. The rainfall is less than 20 % of total precipitation during September and

December which is in coincidence of flowering and boll development stages of cotton. During this period, the top A horizon has low soil water content and reaches to wilting point. The stored water in subsoils is used by crop in times of delay in rains and experiences drought like situations with prolonged dry spells. The water stress occurs when cotton attains early bloom stage and is highly sensitive to water stress. The water content of shrink-swell soils in the region reaches to 20% of available water.

The water retention curve of shrink-swell soils were similar with respect to depth of layers showing decreasing soil water content. The water content decreased at 800kPa as the curves of cambic and slicken sided horizons intersect with each other with soil water values of 25 to 50% from 1 to 800kPa. At field capacity the water suction for top A horizon is 20kPa but of 30kPa for cambic and slicken sided zones (Figure 3). Depending upon the irregularities in soil water movement under hot semiarid climate, the shrink-swell soils experiences the period of wet stage, and alternate wet - dry stages during cotton growing season. The vertical changes in soil water content in the arable black soils was reported that the soil water content varies significantly from the zone of 0-40cm at the rate of 14 to 32 %, weakly varying from 40-110cm with change of 24 to 32%,and slightly varying zone of 110-260cm with change of 4% i.e. from 28 to 32% (Meng, *et al.,* 2004). The change in soil water at 0-20cm during crop growing season (from June to February), rain is the water source to support seedling emergence, and then to primordial branching stage and sensitive to water stress that ultimately influence lint yield. In this region, sowing generally commences with the arrival of the monsoon in the month of June. Late sowing because of the late arrival of the monsoon leads to a significant yield loss due to terminal moisture stress as well as low temperature effect during December and January (Hebbar, *et al.,* 2003). Water-limited (rainfed) seed cotton yield had a positive correlation ($r = 0.52^*$, significant at 5% level) with rainfall, and in Vertisols, rainfed cotton yield is primarily a function of the quantum, and distribution of rainfall (Venugopal *et al.*, 2003). The relationship between water-limited seed cotton yield and saturated hydraulic conductivity(sHC) was quadratic (with an optimum value of sHC of 10.6 mm/h). The sHC and ESP along with $CaCO_3$ in clay fraction and Ca/Mg ratio influenced the yield of rainfed cotton in Vertisols of Central India (Kadu *et al.*, 2003). When dry, the clay soils present moderately deep to deep, dense subsoils with numerous, deep, wide cracks that act as sinks for runoff water immediately after rainfall events. Infiltration rates are extraordinarily high for the entry of the first flush of rain and runoff water ponded on the soil surface, but diminish rapidly as the soil wets up, swells, and its cracks and pores begin to close up. Water infiltration rates as high as 20 mm / hr have been measured on such soils but reduce to less than 2 mm/hr as quickly as a half an hour after the water application commenced (Coventry, 2009).

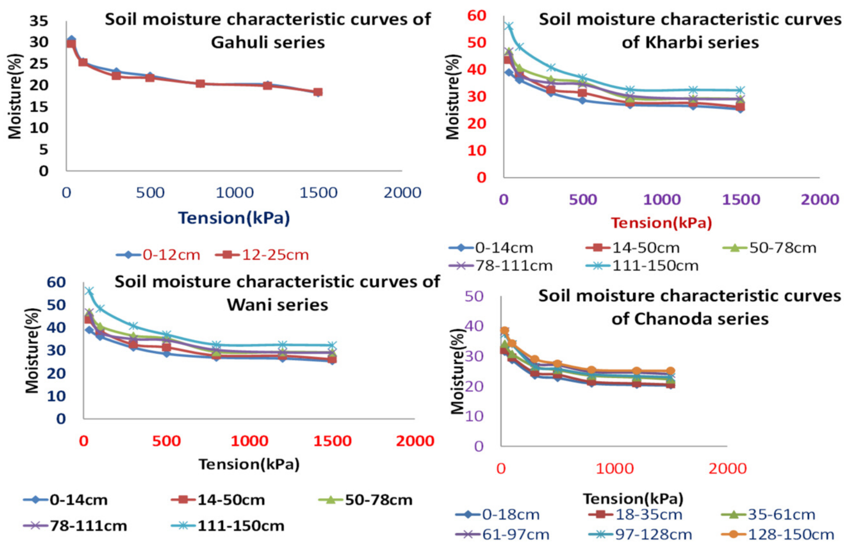

Figure 2 - Soil water retention curves for four major soil series of Yavatmal district.

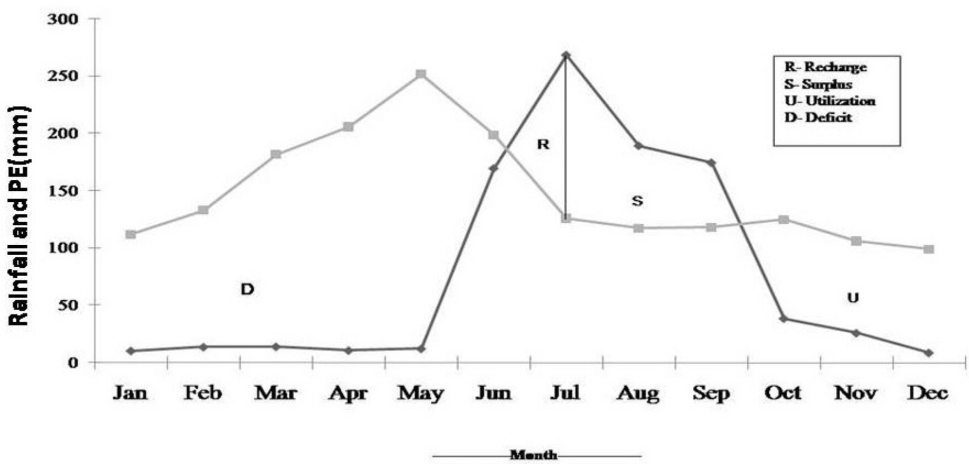

Figure 3 - Water balance diagram of Yavatmal district.

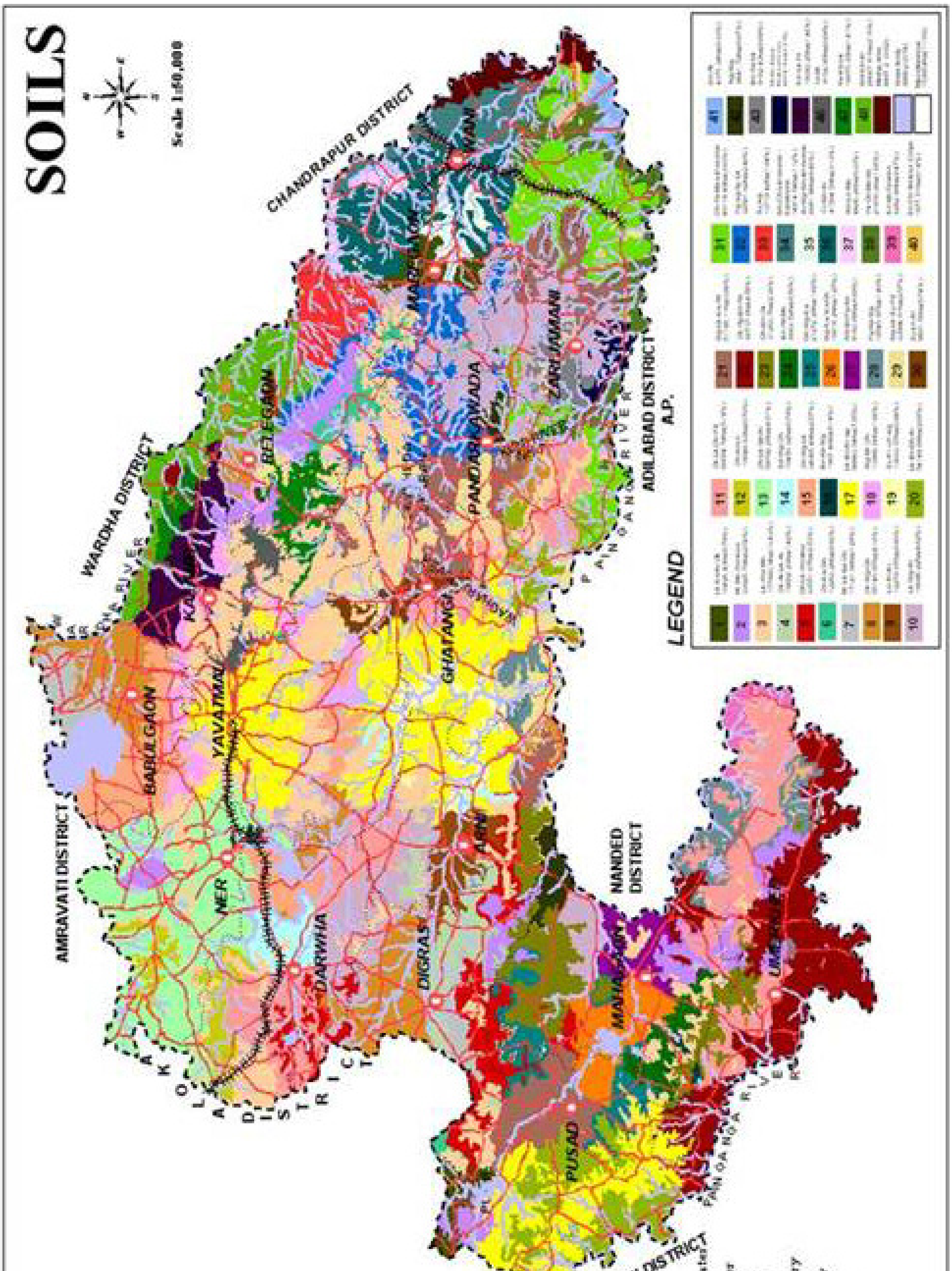

Figure 4 - Soil map of Yavatmal district.

Soil map

The soil mapping units in relation to land forms is presented in Table 7. The area under each landforms shows that middle plateaus cover 17.35 per cent of total area followed by lower pediplains (15.82 per cent), upper pediplains (12.95 per cent), hills and ridges (12.6 per cent), isolated hills (6.81 per cent), and butte and mesas (6.32 per cent) whereas other landforms cover less than 5 per cent of total area in the district. The soil map was generated with 48 soil series associations as mapping units (Figure 4). The soil map shows that the soil mapping unit -3(Lk – Roc-Mo) under middle plateaus covers 12.3 per cent of total area and evaluated as moderately suitable for sorghum and wheat. This mapping unit spread over north and north western parts of Yavatmal and Darwha plateau. The soil mapping unit 17 (Lk-Bo-Ar-Dk) under lower pediplains cover 7.28 per cent of area and evaluated as marginally suitable for cotton and moderately suitable for sorghum and wheat. The Wani valley in eastern part of Yavatmal has soil mapping units from 39 to 48 with small delineations and also have an area less than 1% under each delineations. The soil mapping units under stony gullied wastelands (19, 7, 24, 2.81 per cent of area) is evaluated as unsuitable for cotton cultivation but moderately to marginally suitable for sorghum and soybean. The soil mapping units under hills and ridges, isolated hills and upper plateaus are marginally suitable for cotton.

Soil-site suitability for cotton based cropping systems

The arability analysis shows that the basaltic clays on plateaus, steep escarpments, and stony gullied waste lands along Penganga river are evaluated as non arable. The non arable land accounts to 13.96% of total area (189728 ha) with severe limitations of slopes, stone cover, rock outcrops, shallow soil depth, and poor nutrient status. The district statistics shows that 66% of total area is under cultivation with a land ratio of 1.19 to 1 as against fiber to food crops. Out of total cultivated area, 52 percent of area is under cotton with a 34 % under food crops. Hence land evaluation exercise is totally based on cotton based cropping systems. The soil suitability is related to a three-way interaction between soil type, rainfall characteristics and species/varietal adaptations in Yavatmal district.The cotton on basaltic clay soils in Yavatmal district are well drained with optimal depth of 100cm, calcium carbonate content of 20 per cent, and a rainfall of 1000mm (Sehgal, 1991). Cotton develops well on moderately fertile soils the optimal pH range from 6 to 7.5, and marginal range from 5 to 8 (Sys and Riquire, 1979 and Doorenbos and Kassam, 1979).

The soil mapping units viz., Gh-Lk-RoC (5), Dk-Wg-Gh (28) and Gh-Bo-Dk (23) units cover more than 2% of area accounting to the total of 8.15%. Twenty nine soil mapping units covering 47.14% of total arable land are evaluated for cotton suitability

Table 7- Evaluation of soil-site suitability for cotton, sorghum, soybean and wheat.

S.No /**SMU NO.**	Soil mapping unit	Area		Suitability class			
		ha	%	Cotton	Sorghum	Soybean	Wheat
1.Hills and ridges							
2	Met(Mt)-Moho(Mo)-Rockout crops	34182	2.52	-	S3	-	S2
5	Gahuli (Gh) –Lakhi (Lk) -Rockout crops	33805	2.49	-	-	-	-
20	Lakh(Lk) i-Borgaon (Bo)-Gahuli(Gh)-Arni(Ar)	35415	2.61	S3	-	-	-
21	Waghari(Wg)-Lakhi(Lk)-Kolambi(Ka)-Pandhurna(Pd)	515828	3.80	S3	S2	-	S2
18	Waghari(Wg)-Met(Mt)-Dhanora(Dh)	14094	1.04	-	S3	-	S3
40	Sindola (Sn)– Chanoda(Ch) – Rock outcrops	1892	0.14	S2	S2	S3	S2
Total		**170971**	**12.6**				
2.Upper plateaus							
45	Kalamb (Km)– Lakhi (Lk)– Hirdi(Hi)	19075	1.41	S3	S3	S3	S3
46	Hirdi (Hi)– Met (Mt)	8954	0.66		S3	S3	S3
23	Gahuli(Gh)-Borgaon(Bo)-Dhanki(Dk)	30692	2.26	-	-	-	-
35	Apti (Ai)– Waghari (Wg)– Wani(Wn)	5992.	0.44	S2	S2	-	S2
Total		**64713**	**4.77**				
3.Middle plateaus							
3	Lakhi(Lk)-Rock out crops-Moho(Mo)	167536	12.3		S2	-	S2
13	Dhanora(Dh)-Lakhi(Lk)-Selodi(Sd)-Arni(Ar)	59357	4.37	S3	S2	-	S2
43	Borgaon (Bo)– Ralaegaon (Ra)– Lakhi(Lk)	9162	0.68	S3	S2	-	S2
Total		**241218**	**17.35**				
4.Lower plateaus							
22	Dhanki(Dk)-Penganga(Pg)-Borgaon (Bo)-Pandhurna(Pd)	59970	4.42		S1	-	S1
1	Lakhi (Lk)-Kalamb (Km)-Arni (Ar)-Dhanki(Dh)	10295	0.76	S3	-	-	-
25	Gahuli(Gh)-Waghari(Wg)- Katherwadi(Kw)	21004	1.55	-	S2	S3	S2
39	Korta (Ko)– Kharbi(Kb)	6203	0.46	S3	S2	S3	S2
Total		**97472**	**7.19**				
5.Isolated hills							
11	Dhanki(Dh)-Lakhi(Lk)-Dhanora(Dh)-Pandhurna(Pd)	67925	5.01	S3	S2	S3	S2
6	Dhanora(Dh)-Kolambi(Ka)i-Gahuli(Gh)	12260	0.90	-	-	-	-
9	Loni(Lo)-Arni(Ar)-Arunavathi(Av)	12256	0.90	S2	S2	S3	S2
Total		**92441**	**6.81**				
6.Butte and Mesas							
8	Dhanki(Dk)-Waghari(Wg)-Gahuli(Gh)	53868	3.97	-	-	-	-
32	Penganga(Pg)-Waghari(Wg)-Saykheda(Sy)-Lakhi(Lk)	31829	2.35	S3	S2	S3	S2
Total		**85696**	**6.32**				
7.Escarpments							
36	Chikhalgaon(Ci)-Wani(Wn)-Apti(Ai)	41070	3.03	S2	S2	-	S2
38	Pandharkawda(Pk)-Chanoda(Ch)-Maregaon(Ma)-Wanjari(Wj)	21647	1.60	-	S3	-	S3
Total		**62717**	**4.63**				
8.Upper pediplains							
12	Dhanora(Dh)-Arni(Ar)-Loni(Lo)	10122	0.75	S2	S2	-	S2
34	Wani(Wn)-Chanoda(Ch)	15024	1.11	S2	S2	S3	S2
48	Wanodi(Wd)-Kharbi(Kb)-Arni(Ar)	28878	2.13	S3	S2	S3	S2
14	Selodi(Sd)-Waghari(Wg)-Dhanora(Dh)	10527	0.78	S2	S2	-	S2
47	Ralaegaon(Ra)-Kharbi(Kb)-Lakhi(Lk)	18843	1.39	S3	S2	S3	S2
26	Waghari(Wg)-Katherwadi(Kw)-Kolambi(Ka)-Gahuli(Gh)	16740	1.23	-	-	-	-
33	Saykheda(Sy)-Waghari(Wg)	13820	1.02	S1	S1	S3	S1
10	Lakhi(Lk)-Waghari(Wg)-Arni(Ar)	61647	4.54	S3	S3	S3	S3
Total		**175600**	**12.95**				
9.Lowerpediplains							
17	Lakhi(Lk)-Borgaon(Bo)-Arni(Ar)-Dhanki(Dk)	98771	7.28	S3	S2	-	S2
29	Waghari(Wg)-Lakhi(Lk)-Saykheda(Sy)-Pandhurna(Pd)	335821	2.47	S3	S2	S3	S2
31	Chanoda(Ch)-Pandharkawada(Pk)-Maregaon(Ma)	39633	2.92	-	S3	-	S3
15	Dhanora(Dh)-Waghari(Wg)-Lakhi(Lk)	33672	2.48	S3	S2	-	S2
27	Wanodi(Wn)-Borgaon(Bo)-Penganga(Pg)-Kolambi(Ka)	9072	0.67	S3	S1	-	S1
Total		**214730**	**15.82**				

Table 7 - continued

S.No /**SMU NO.**	Soil mapping unit	Area		Suitability class			
		ha	%	Cotton	Sorghum	Soybean	Wheat
10.Intervening valleys							
4	Dhanki(Dk)-Arni(Ar)-Lakhi(Lk)-Arunavati(Av)	19087	1.41	S3	S2	-	S2
28	Penganga(Pg)-Kolambi(Ka)-Waghari(Wg)	18827	1.39	S3	S1	S3	S1
30	Saykheda-Loni-Arni	9950	0.73	S2	S2	-	S2
Total		**47865**	**3.53**				
11. Stony gullied waste lands							
19	Saykheda(Sy)-Met(Mt)-Jamwadi(Jam)-Waghari(Wg)	13489	0.99	-	S3	S3	S3
7	Met(Mt)-Lakhi(Lk)-Kolambi(Ka)-Dhanki(Dk)	17718	1.31	-	S3	S3	S3
24	Borgaon(Bo)-Pandhurna(Pd)-Moho(Mo)	6896	0.51	-	S2	-	S2
42	Nagdhari(Ng)-Waghari(Wg)	9150	0.67	S2	S2	S3	S2
Total		**47253**	**3.48**				
12.Moderately to gently sloping lands							
31	Chanoda(Ch)-Pandharkawda(Pk)-Maregaon(Ma)	41274	3.04	-	S3	-	S3
37	Wani(Wn) – Loni(Lo) – Maregaon(Ma)	4554	0.34	S2	S2	-	S2
Total		**458268**	**3.38**				
13.Gently to very gently sloping lands							
16	Borgaon(Bo)-Kolambi(Ka)-Waghari(Wg)	2665.306	0.20	S2	S1	-	S1
41	Sindola(Sn) – Pandharkawda(Pk)	6113.691	0.45	-	S3	S3	S3
44	Pandharkawda (Pk)– Sindola(Sn)	6880.603	0.51	-	S3	S3	S3
Total		**15659.6**	**1.16**				

(Figure 5). Twleve soil mapping units (9, 30, 40, 42, 33, 34, 12, 16, 14, 35, 36 and 37) are evaluated as moderately suitable for cotton (19.8%) and 17 soil mapping units (1, 4, 10, 11, 29, 32, 45, 47, 48, 28, 39, 13, 15, 17, 21, 27 and 43) as marginally suitable (27.33%, Table 4). It is also estimated that 15 soil mapping units *viz.*, 1, 4, 9, 10, 11, 28, 33, 34, 39, 13, 15, 35, 36, 37 and 22 covering 16.24 % of arable land (2,42,278 ha) are suitable for sugar cane, 13.23 % for redgram (197289 ha) and 33% for groundnut. Generally redgram is grown in kharif as intercrop with cotton in the ratio 1:8 or 1:12 bur very rarely seen as sole crop. The groundnut is grown during summer under canal or well irrigated tracts of Pus, Wardha and Painganga valley.

Cotton yield

The plateaus in Yavatmal cover approximately about 40 % of total geographical area. These plateaus support Typic/Leptic Haplusterts, Typic/Lithic Haplustepts, Typic and Lithic Ustorthents. The very deep Typic Haplusterts have cotton yields of 25 to 30 q/ha to 18 -25 q/ha in pediplains under dry land conditions where as 12.5 to 15q/ha in Typic Haplustepts, and 2 to 4 q/ha in Lithic Ustorthents (Table 8). The soil survey data sets help to identify the high yield areas under a define set of management, and tries to link soil types with crop productivity data sets which are helpful for technology transfer based on soil analogy. The soil- crop link is possible by knowing yield variations under rainfed conditions, and identify the yield gaps of cotton specially in this region.

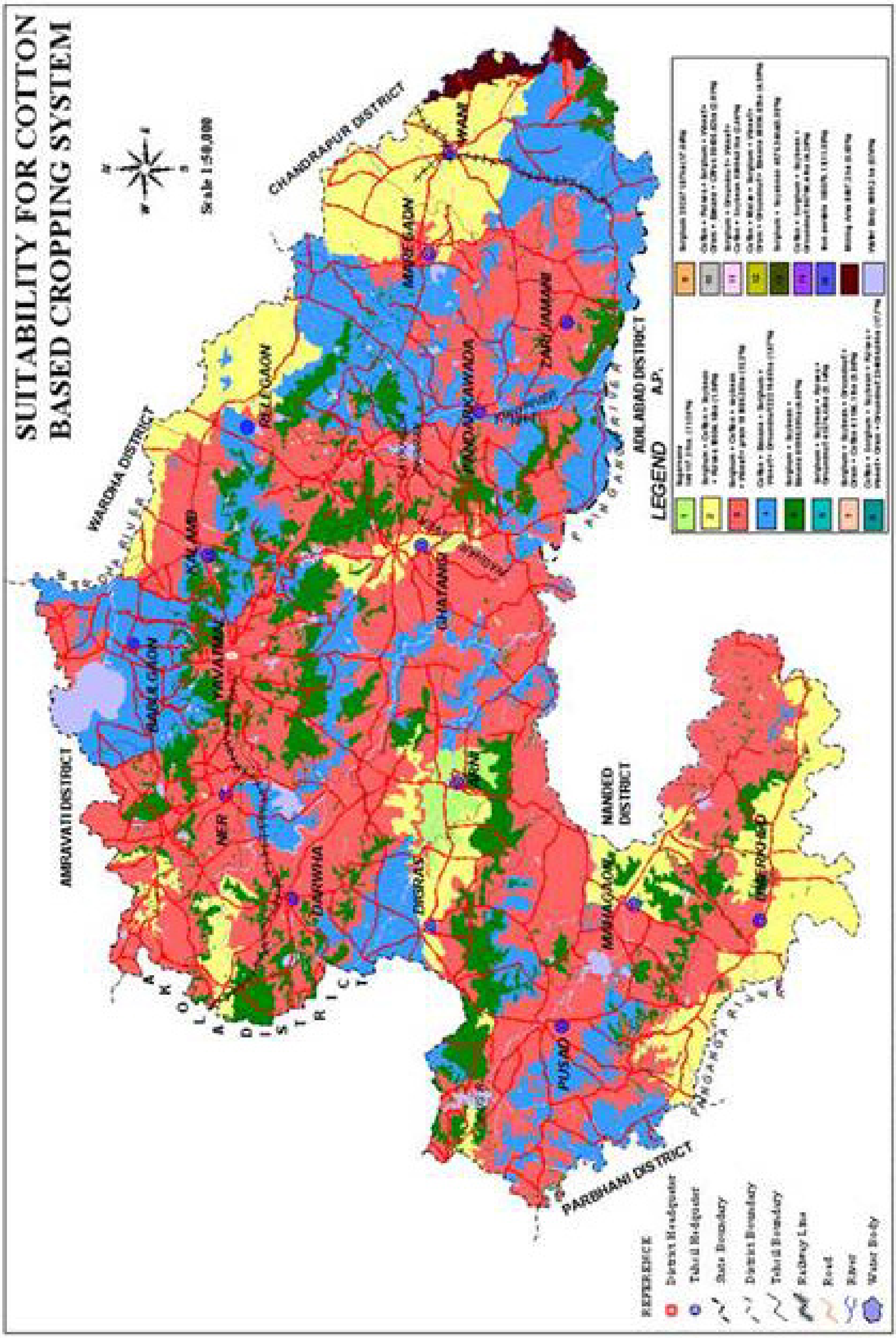

Figure 5 – Soil site suitability map for cotton based systems.

Table 8 - Cotton yield trends with respect to land forms and soil taxonomy.

Soil Subgroups	Elevation(m)		Soil Depth(cm)		Cotton(q/ha)		
	Mean ±SD	CV(%)	Mean± SD	CV(%)	Plateaus	Pediplains	Plains
Lithic Ustorthents	375.6±32.2	8.6	18.7±17.4	92.7	2.5-5.0	3-6	4-6
Typic Ustorthents	347.1±13.8	3.9	47.7±12.8	26.8	5-7	4-7	6-9.5
Lithic Haplustepts	345.2±25.1	7.3	31.6±9.6	30.4	10-12	5-7.5	7-9
Typic Haplustepts	358.6±34.3	9.6	63.9±28.5	44.6	12.5-15	12-14	12.5-15
Leptic Haplusterts	344.0±13.4	3.9	89.4±32.6	36.5	17-20	20-25	10-12.5
Typic Haplusterts	334.8±35.7	10.7	139.5±16.5	11.8		18-25	20-25

Available NPK and DTPA extractable micro nutrient status of soils

The available NPK status of 33 soil series identified in Yavatmal district shows that these soils are deficient in available nitrogen and phosphorus and medium to high in available potassium (Table 9). The soil test values for available nitrogen and phosphorus is below the critical limits mentioned for black soils in India (Tandon, 2004). This observation is in agreement with the earlier reports of fertility status of black soils in India (Rao *et al.*, 1997). The low status of nitrogen in these soils may be due to retention of ammonium on clay exchange complex because of similar size, charge, and hydration energy to that of potassium, inability to compete with calcium on exchange sites and of losses due to voltalization and denitrification of nitrate after bacterial transformations (Sparks, 1980). The low P status is due to adsorption of P on $CaCO_3$ and inability of Olsen's extractant (Shreepad 1999). Poor fertility of these soils is mainly due to crop intensification in medium, and deep black soils and off high yielding Bt cotton cultivation over large areas. Based on K content (Mars *et al.*, 1999), these soils are grouped as (i)low (<150mg/kg) :- Arni, Apti, Chanoda, Gahuli, Jamwadi, Korta, Loni, Met, Pandhurna, Pandharkawda, Waghari, Wani, and Wanjari and (ii)medium (150-250mg/kg):- Arunavati, Borgaon, Chikhalgaon, Dhanora, Dhanki, Kolambi, Katherwadi, Lakhi, Maregaon, Penganga, Saykheda, Selodi and Wanodi.

The profile distribution of DTPA extractable iron shows slight variations with depth but below critical limit (<4.5 mg/kg, Shukla *et al.*, 2012) is recorded in Kalamb, Nagdhari, Pandhurna , Ralaegaon and Sindola soils where as in other soils, DTPA extractable iron is medium (4.5 to 7 mg/kg).The manganese content ranges from 0.32 mg/kg in Bw2 horizons of Ralaegaon to 16.96 mg/kg in Ap horizons of Waghari and Saykheda (Table 9). The Nagadhari and Ralaegaon soils have manganese content below critical limit (<1.2 mg/kg). The profile distribution of manganese is almost similar to that of Fe showing slight variations with depth. These soil have very high (>3 mg/kg) contents of DTPA extractable Cu showing decreasing trends with depth. Its content varies from 2.22 to 16.12. The DTPA extractable Zn shows decreasing trend with its values varying from 0.19mg/kg (P12) to 2.23mg/kg (P8). The Zn contents

Table 9 - Available NPK and DTPA extractable micronutrient status in soils.

Soil series	Depth(cm)	Horizon	Available (mg/kg)			DTPA extractable (mg/kg)			
			N	P	K	Fe	Mn	Cu	Zn
1. Arunavati	0-19	Ap	50.6	0.5	225.0	5.8	8.7	4.5	0.9
	19-55	Bk1	44.8	0.5	70.0	5.9	6.7	3.2	0.7
	55-95	Bk2	16.8	0.5	53.0	7.6	6.1	2.2	0.6
2. Arni	0-18	Ap	60.0	3.0	130	4.7	9	3.7	1.0
	18-37	Bw	39.2	1.6	62.5	4.8	7.2	3.7	0.9
	37-63	Bss1	33.6	1.3	62.5	4.9	7.3	3.6	0.8
	63-94	Bss2	33.6	1.3	55.0	5.3	7.3	3.5	0.8
3. Apti	0-13	Ap	28.0	1.5	82.5	7.3	7.9	4.7	0.5
	13-33	Bw	72.8	1.0	45.0	7.2	7.5	4.5	0.6
	33-70	Bss1	61.3	0.5	40.0	7.5	8.1	5.1	0.8
4. Borgaon	0-16	Ap	56.0	1.3	160.0	5.6	9.9	4.1	0.4
	16-35	Bw1	61.3	0.5	155.0	5.7	8.3	4.3	0.9
	35-54	Bw2	44.8	0.5	155.0	5.6	8.3	4.0	0.9
	54-67	Bw3	16.8	0.5	110.0	5.5	7.7	2.7	0.9
5. Chikhalgaon	0-13	Ap	50.4	1.3	235.0	6.4	8.1	4.0	1.5
	13-41	Bw	39.2	0.7	142.5	6.5	9.1	3.5	0.8
	41-74	Bss1	33.6	0.5	142.5	6.3	7.5	3.6	0.8
	74-95	Bss2	22.4	0.5	150.0	6.6	7.6	3.1	0.8
6. Chanoda	0-13	Ap	50.4	1.3	72.5	7.0	7.8	4.3	0.7
	13-28	Bw	50.4	1.0	57.5	7.2	10.2	4.8	1.0
	28-60	Bss1	44.8	0.5	55.0	7.1	8.6	4.3	0.7
	60-98	Bss2	28.0	1.0	60.0	7.2	8.3	4.3	0.7
	98-150	Bss3	39.2	1.0	52.5	6.9	7.8	4.5	0.8
7. Dhanora	0-13	Ap	28.0	1.0	192.5	5.0	8.7	5.0	1.1
	13-30	Bw	33.6	0.5	122.5	4.8	7.8	3.7	1.0
8. Dhanki	0-15	Ap	61.6	7.5	207.5	7.6	17.8	6.4	0.5
	15-40	Bw	22.4	1.6	150.0	6.9	17.5	16.1	2.2
	40-75	Bss1	33.6	0.9	145.0	7.1	12.8	5.1	0.7
	75-115	Bss2	28.0	0.6	152.5	7.3	9.1	4.8	0.9
	115-170	Bss3	25.3	0.6	177.5	7.3	7.9	4.7	0.7
9. Gahuli	0-17	Ap	36.3	4.5	168.1	7.4	16	5.5	0.4
10. Hirdi	0-12	Ap	33.8	4.3	239.3	11.6	1.2	5.0	0.6
	12-32	Bw	10.2	0.4	112.9	9.0	1.0	6.9	0.6
	32-75	Bss	6.6	0.2	53.4	5.9	6.6	7.0	0.6
11. Jamwadi	0-20	Ap	61.6	2.0	150.0	8.0	23.8	6.8	1.4
	20-40	Bw1	50.4	1.3	125.0	7.7	63.7	6.6	1.7
12. Kalamb	0-20	Ap	63.3	2.5	284.8	1.4	4.0	2.6	0.2
	20-41	Bw	60.2	1.3	222.3	1.1	2.3	1.5	0.2
	41-70	Bss1	60.5	0.4	141.3	1.0	1.7	2.3	0.3
	70-96	Bss2	49.5	0.1	134.2	1.2	1.9	2.5	0.3
	96-114	Bss3	41.5	0.1	189.6	1.7	1.8	2.5	0.3
	114-150	Ck	37.6	0.2	53.82	1.0	0.7	1.3	0.2
13. Kolambi	0-20	Ap	67.2	2.5	207.5	7.4	51.1	7.0	1.4
	20-47	Bw1	50.4	1.0	162.5	6.9	10.8	6.5	1.0
	47-89	Bw2	44.8	1.0	95.0	7.6	8.0	4.9	0.8
14. Katherwadi	0-12	Ap	78.5	1.3	217.5	7.1	7.6	4.9	0.7
	12-28	Bw1	95.2	1.0	177.5	7.1	8.0	4.7	0.8
	28-49	Bw2	61.6	0.5	202.5	7.4	9.3	5.9	1.0
	49-72	Bss1	56.0	0.5	217.5	7.4	8.6	5.9	0.8
	72-96	Bss2	49.4	0.7	195.0	7.2	12.6	6.0	0.7

Table 9 - continued

Soil series	Depth(cm)	Horizon	Available (mg/kg)			DTPA extractable (mg/kg)			
			N	P	K	Fe	Mn	Cu	Zn
15. Korta	0-20	Ap	67.2	0.5	127.5	5.6	40.4	6.2	1.2
	20-50	Bw	33.6	0.5	112.5	5.4	15.0	5.2	1.1
	50-60	Cr	44.8	0.5	77.5	5.2	8.6	4.1	1.0
16. Kharbi	0-20	Ap	78.4	3.0	331.2	5.0	11.5	3.0	1.0
	20-50	Bw	50.4	3.5	192.9	5.3	9.1	2.9	0.8
	50-70	Bss1	39.2	1.5	221.3	5.4	8.2	2.8	0.8
	70-100	Bss2	33.6	4.0	170.7	5.4	7.7	2.7	0.8
	100-130	Bss3	19.5	1.6	173.3	5.2	7.5	2.5	0.9
17. Loni	0-15	Ap	67.2	1.3	160.0	6.6	13.3	5.6	1.4
	15-40	Bw1	11.2	1.0	102.5	6.2	9.3	4.6	0.8
	40-74	Bss1	22.4	1.0	105.0	6.4	6.5	4.1	0.7
	74-106	Bss2	22.4	1.0	152.0	6.4	6.7	4.2	0.7
	106-150	Bss3	33.6	1.0	200.0	6.5	6.3	4.2	0.7
18. Lakhi	0-26	Ap	45.2	1.5	227.0	7.8	8.5	6.0	0.7
19. Met	0-20	Ap	78.4	4.7	122.5	8.0	24.5	7.1	1.5
20. Moho	0-7	A	94.1	3.6	294.0	10.5	43.8	14.1	1.5
	7-23	AC	36.8	1.2	142.5	8.7	47.5	12.0	0.9
21. Maregaon	0-15	Ap	56.0	1.5	227.5	6.5	9.8	4.8	0.9
	15-42	Bw	50.4	1.0	35.0	6.4	7.6	4.4	0.7
22. Nagdhari	0-18	Ap	21.03	0.3	196.0	1.2	3.3	0.7	0.6
	18-43	Bw1	55.5	0.5	133.2	1.0	1.0	1.4	0.5
	43-64	Bw2	61.9	0.2	145.5	1.4	0.3	1.3	0.4
	64-85	Bw3	37.6	0.2	135.4	1.1	1.0	1.3	0.6
	85-110	Bw4	36.7	0.1	135.6	1.0	0.9	1.5	0.3
	110-144	Bw5	13.8	0.2	113.1	1.0	1.1	1.6	0.3
23. Pandhurna	0-13	Ap	56.0	1.5	130.0	6.1	11.3	5.1	0.8
	13-38	Bw1	44.8	0.5	100.0	5.1	10.8	7.6	0.8
	38-62	Bw2	44.8	0.5	52.5	5.9	9.1	6.7	0.7
	62-87	Bw3	39.2	1.0	80.0	6.2	9.0	5.2	0.8
	87-150	Bw4	27.9	0.5	105.0	5.7	8.0	6.9	0.8
24.Pandharkawada	0-11	Ap	29.3	4.7	77.5	7.5	11.6	5.4	0.7
25. Penganga	0-15	Ap	44.8	1.5	142.5	5.2	9.0	3.9	1.0
	15-50	Bw	33.6	0.5	207.5	5.6	7.8	3.5	0.9
	50-85	Bss1	39.2	0.9	205.0	5.5	7.5	3.3	0.9
26. Ralaegaon	0-15	Ap	31.9	4.9	299.1	1.0	3.1	2.0	0.1
	15-42	Bw	18.2	1.3	131.9	0.7	0.3	0.3	0.2
	42-70	Bss1	11.7	0.4	102.8	0.4	0.6	0.2	0.2
	70-84	BC	22.2	0.8	111.89	1.5	1.1	0.1	0.4
27. Saykhed	0-19	Ap	72.8	2.0	207.5	6.0	17.0	4.4	0.8
	19-47	Bw	44.8	0.5	187.5	6.0	8.5	3.9	0.8
	47-82	Bss1	50.4	0.6	102.5	5.7	6.7	3.5	0.7
	82-118	Bss2	33.6	0.5	82.5	6.7	7.1	2.8	0.8
	118-150	Bss3	33.6	0.5	97.5	7.2	7.1	3.0	0.8
28. Selodi	0-12	Ap	61.2	1.3	127.5	7.0	9.3	5.8	1.1
	12-38	Bw1	56.0	0.5	237.5	7.1	9.1	5.8	0.9
	38-71	Bss1	39.2	0.5	225.0	6.9	8.9	5.5	0.8
	71-103	Bss2	33.6	0.5	230.0	7.3	9.7	5.5	0.9
	103-150	Bss3	39.2	0.5	215.0	7.2	9.5	5.4	0.8
29. Sindola	0-12	Ap	34.4	17.6	346.4	1.4	10.7	3.5	0.1
	12-25	Bw1	12.6	1.0	132.4	1.7	5.5	1.6	0.1
	25-52	Bw2	13.3	0.7	150.6	1.4	3.7	1.3	0.4

Table 9 - continued

Soil series	Depth(cm)	Horizon	Available (mg/kg)			DTPA extractable (mg/kg)			
			N	P	K	Fe	Mn	Cu	Zn
30. Waghari	0-19	Ap	29.7	11.4	153.2	6.1	17.0	4.4	0.8
	19-48	Bw	18.1	0.5	55.4	6.0	8.5	5.9	0.8
31.Wanodi	0-15	Ap	78.4	2.0	160.0	7.5	9.4	6.7	0.7
	15-42	Bw	33.6	0.5	160.0	7.5	7.8	5.1	0.2
	42-72	Bss1	22.4	0.5	207.5	7.3	12.2	5.6	1.1
	72-98	Bss2	44.8	0.5	160.0	7.2	9.4	5.1	0.7
	98-152	Bss3	35.7	0.5	192.5	7.3	7.0	4.3	0.6
32.Wani	0-12	Ap	22.4	3.0	170.0	6.0	13.2	4.4	0.9
	Dec-42	Bw	39.2	0.5	137.5	6.1	7.7	4.6	0.8
	42-70	Bss1	33.6	0.5	142.5	6.1	7.6	4.9	0.7
	70-101	Bss2	28.0	0.6	147.5	6.2	7.6	4.9	0.8
	101-140	Bss3	28.0	0.8	145.0	6.5	7.8	5.3	0.8
33.Wanjari	0-13	Ap	43.4	1.1	122.9	7.5	7.7	4.4	0.7
	13-40	Bw1	18.8	0.1	137.8	7.3	8.4	4.5	0.6

below critical limit (<1mg/kg) is observed in six soil series viz., Gahuli (P9), Kalamb (P12), Nagdhari (P22), Ralaegaon (P26), Sindola (P29) and Wanodi (P31) but in other soils, zinc is medium. It was in agreement with the earlier reports that most of the vertisol fields are low in N, P, and Zn, and in some of them after addition of about 1,000 kg of P, in 8 years, the level of "available" phosphorus in the soil had not increased above the medium level, as indicated by the available P value obtained by Olsen's method. Deficiency of zinc after land treatments becomes even more manifest, and needs occasional application of zinc sulfate to attain satisfactory yields of crops. The failure to recognize the nutrient deficiency, and changes in availability of soil and fertilizer nitrogen with season and management has serious implications for the realization of the production potential from these soils (Kanwar, 1982).

Soil grouping for NPK recommendations

The dendrogram shows five distinct groups of SMU's in relation to landforms. The group-1 includes five units including two units of intervening valleys (Dk-Ar-Lk-Av and Sy-Lo-Ar) in association with units of lower plateaus (Dk-Pg-Bo-Pd), hills and ridges (Wg-Lk-Ka-Pd), and butte/mesas (Pg-Wg-Sy-Lk). These units are mostly occurred in Yavatmal plateaus of northern parts of the district. Likewise Group-II includes seven units consisting three units of lower pediplains (Ch-Pk-Ma-roc, Wg-Lk-Sy-Pd and Lk-Ka-Ar-Dk) associated with isolated hills (Dk-Lk-Dh-Pd), escarpments (Ci-Wn-Ai), and upper plateaus (Gh-Bo-Dk). This group of soils is geographically distributed in south eastern parts of Pus/Penganga valleys. Six units of Group - III and Group - IV are mostly occurring in plateaus, moderately to gently sloping lands of north western parts covering Arni, Ghatanji and Arunavathi regions of Darwha / Yavatmal. The seven units of Group - V are spread over the entire district

Table 10 - Rate of fertilizer application as per soil groups and land forms for cotton.

SMU	Land forms	Rate of fertilizer (kg/ha)		
		FN	FP_2O_5	FK_2O
Group-1				
Dk-Pg-Bo-Pd	Lower plateaus	125.06	88.06	62.04
Wg-Lk-Ka-Pd	Hills and ridges	127.67	90.79	63.65
Pg-Wg- Sy-Lk	butte and mesa	108.41	77.63	70.22
Dk - Ar -Lk- AV	Intervening valleys	133.72	62.22	67.9
Sy -Lo-Ar	intervening valleys	120.35	93.75	56.98
Mean		**123**	**82**	**64**
SD		**9.5**	**13**	**5**
CV(%)		**7.7**	**16**	**8**
Group2				
Dk-LK-Dh-Pd	isolated hills	134.82	51.69	76.67
Ci- Wn -Ai	Escarpments	140.64	91.28	71.33
Ch-Pk-Ma-Limestone	lower pediplains	145.93	89.31	78.62
Sy-Mt-Jm-Wg	stony gullied land	142.78	56.49	68.38
Wg-Lk- Sy -Pd	Lower pediplains	138.56	58.88	59.74
Lk-Ka-Ar -Dk	Lower pediplains	138.05	55.93	66.7
Gh-Bo-Dk	upper plateaus	134.11	84.73	63.14
Mean		**139**	**70**	**69**
SD		**4.2232**	**17.71**	**6.859**
CV(%)		3.0324	25.39	9.909
Group3				
Dh-Wg-Lk	lower pediplains	109.13	32.07	65.14
Lk-Wg-Ar	upper pediplains	148.04	45.21	73.19
Bo-Ka-Wg	gently to very gently sloping lands	137.94	87.22	37.44
Pg-Ka-Wg	intervening valley	133.6	72.64	41.13
Dh- LK-Sd -Ar	middle plateaus	146.39	91.12	45.54
Ko-Kb-Granite	lower plateaus	140.94	90.83	41.37
Mean		**136**	**70**	**51**
SD		**14**	**25**	**15**
CV(%)		10.44	36.43	29.23
Group4				
Wd-Bo-Pg-Ka	lower pediplains	129.4	91.42	52.72
Wn-Lo -Ma	moderately to gently sloping	126.99	49.52	51.49
Pk -Ch-Ma- Wj	escarpments	139.57	56.3	55.03
Ra-Kb-Lk	upper pediplains	128.08	45.61	50.09
Sd-Wg-Dh	upperpediplains	133.51	86.34	49.79
Sn-Ch-ROC	hills and ridges	138.73	93.47	52.89
Mean		**133**	**70**	**52**
SD		**5.5**	**22**	**2**
CV(%)		**4.1**	**32**	**4**
Group 5				
Bo-Pd-Mo	stony gullied waste land	112.38	45.77	50.4
Sy -Wg	upper pediplains	133.4	81.8	32.88
Dh-Ar-Lo	upperpediplains	134.17	95.17	77.89
Hi-Mt	upper plateaus	121.08	92.72	68.04
Lk-Bo-Ar-Dk	lowerpediplains	120.85	81.03	98.83
Wg-Mt-Dh	hills and ridges	135.81	74.12	94.21
Km-Lk-Hi	Upper plateaus	141.56	64.14	5.096
Mean		**128**	**76**	**61**
SD		**10.4**	**17**	**34**
CV(%)		**8.1**	**22**	**56**

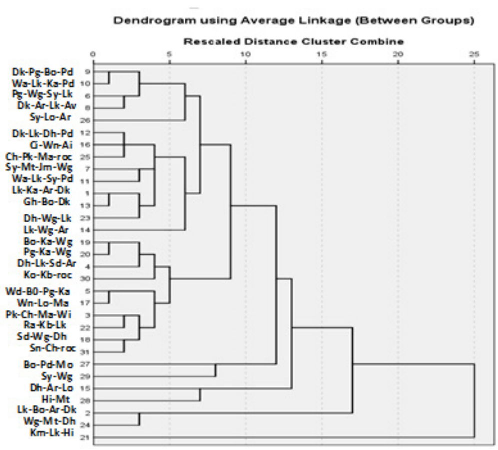

Figure 6 - Soil management groups for NPK recommendations.

bur mostly found in Ralaegaon, Pandharkawada and Wani valleys of southern region (Figure 6).

Based on soil test and crop response studies, to attain a target yield of 15Q/ha of Bt cotton in basaltic and related forms of cotton growing Yavatmal district, these mapping units are evaluated to work out rate of NPK to be applied for each unit as against blanket recommendation of 120:60:60 NPK kg/ha. The regression equations developed for the region were used for computing fertilizer required for each unit (Gudadhe *et al.,* 2011) The mean rate of fertilizer nitrogen application among soil groups varied from 123 kg/ha for Group-I soils to 141.56 kg/ha for Group -V soils but for phosphorus, the rate of application varies from 64 kg/ha for Group-V soils to 83kg/ha for Group -I soils and for potassium , it varies from 51 kg/ha for Group III to 69 kg/ha for Group-II soils (Table 10). The soil-landform information helps in revising fertilizer schedule for attaining target yield of cotton in conjunction with the field experiments and soil test – crop response equations. The study further emphasizes on mapping unit approach for nutrient management strategies for cotton in Yavatmal district.

Conclusion

The interplay between geomorphology and pedology in tandem with climate plays a significant role in agricultural production systems at regional scale. Regional landscape analyses indicate that basaltic terrain limitations prevent cropping activities. The land suitable for cotton is 17.9% with 25.63% of area as marginally suitable. The cotton yield variations with respect to landforms and soil depth is evident with field data but efforts must put up in future crop yield surveys to consider to collect data sets in relation to elevation and soil depth parameters. This study further emphasizes on crop diversification and expansion of food crops in assured irrigated tracts of Pus, Wardha and Penganga valleys. As the district has around 40 % of area under very deep to moderately deep vertic subgroups and vertisols with land capability class - II, which requires conservation tillage with buffer strips and careful management of fertilizers. The remaining 60% shallow soil associations (Lithic subgroups) on steep lands have capability class VII. These soils are used for low input grain production in times of delayed monsoon (risk for grain production is 60 to 80%) and most of the area must be kept under forest. The land evaluation exercises for cotton productivity programmes in the region must be coupled with the conservation techniques.

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