SOIL QUALITY ASSESSMENT IN RAINFED COTTON GROWING ENVIRONS OF TWO AGROECOLOGICAL REGIONS OF VIDARBHA, MAHARASHTRA

THESIS

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DECLARATION OF STUDENT

I hereby declare that the experimental work and its interpretation of the thesis entitled **"SOIL QUALITY ASSESSMENT IN RAINFED COTTON GROWING ENVIRONS OF TWO AGROECOLOGICAL REGIONS OF VIDARBHA, MAHARASHTRA"** or part thereof has not been submitted for any other degree or diploma of any University, nor the data have been derived from any thesis / publication of any University or Scientific Organization. The source of materials used and all assistance received during the course of investigation have been duly acknowledged.

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CERTIFICATE

This is to certify that the thesis entitled **"SOIL QUALITY ASSESSMENT IN RAINFED COTTON GROWING ENVIRONS OF TWO AGROECOLOGICAL REGIONS OF VIDARBHA, MAHARASHTRA"** submitted in partial fulfillment of the requirements for the degree of **"Doctorate of Philosophy in Agriculture (Soil Science and Agricultural Chemistry - Land Resource Management)"** of the Dr. Panjabrao Deshmukh Krishi Vidhyapeeth, Akola is a record of bonafide research work carried out by **Pable Dhanashree Sureshrao** under my guidance and supervision.

The subject of the thesis has been approved by the Student's Advisory Committee.

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(C) LIST OF ABBREVIATIONS

Abbrevations		Expanded form
%	:	Per cent
μm	:	Micrometer
°C	:	Degree Centigrade
/	:	Per
@	:	At the rate of
AAS	:	Atomic Absorption Spectrophotometer
cm	:	Centimeter
c mol(p+)kg^{-1}	:	Centi moles proton donar per kilogram
cfu	:	Colony forming unit
CD	:	Critical difference
CV	:	Coefficient of variation
dSm^{-1}	:	Deci Simens per metre
et al	:	Et alia (and others)
etc.	:	Etcetera
Fig	:	Figure
FYM	:	Farmyard manure
g	:	Gram
ha	:	Hectare
hr	:	Hour
HCl	:	Hydrochloric acid
i.e.	:	That is
kg	:	Kilogram
LGP	:	Length of growing period
M	:	Moist
MAR	:	Mean Annual Rainfall
MAT	:	Mean Annual Temperature
Mgm^{-3}	:	Mega gram per metre cube

mm	:	Millimeter
mg	:	Miligram
PET	:	Potential Evapo-transpiration
PSD	:	Particle size distribution
SAT	:	Semi Arid Tropics
SD	:	Standard deviation
SE(m)	:	Standard error of mean
SQ	:	Soil Quality
TGA	:	Total Geographical Area
t ha^{-1}	:	tonne per hectare
YR	:	Yellowish Red
yr	:	Year

(D) THESIS ABSTRACT

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ABSTRACT

The thesis presents an assessment of soil quality in cotton growing environs (AESR 6.3 and AESR 10.2) of Vidarbha, Maharashtra. Six soils each in AESR 6.3 (Akola district) and AESR 10.2 (Nagpur district) were selected, studied for their morphological, physical, chemical and biological properties and assessed for their quality.

Minimum datasets (MDSs) required for assessing soil quality were developed using i) expert knowledge and ii) Principal Component Analysis (PCA). The major soil constraints identified in AESR 6.3 were shallow depth, high BD, low hydraulic conductivity and high ESP and those in AESR 10.2 were high clay content, high BD and low hydraulic conductivity. The MDS developed by expert knowledge was used in developing Relative Soil Quality Index (RSQI) and Composite Soil Index (CSI) by conventional and fuzzy modeling-based method respectively. PCA was also used in developing MDS, followed by use of a (contemporary) PCA-based method for soil quality assessment through Soil Qualiy Index (SQI). The results indicate that all the methods identified pedon 3 and pedon 12 as the best soil (rank 1) in AESR 6.3 and AESR 10.2 respectively. The PCA-based method was identified as the best method of soil quality assessment in AESR 6.3 whereas conventional method was superior to other methods in AESR 10.2.

CHAPTER - I

INTRODUCTION

1.1 Background Information

The concern for agricultural sustainability and food security that started growing in the twentieth century has assumed more serious proportions in the 21st century. It has been due to, among other factors, the continually and rapidly limiting arable land resources as a result of their degradation, a major global issue, rapidly increasing world population especially in developing countries of tropics and subtropics, (mis)use of agricultural land for non-agricultural purposes, intensification of cropping, decline of good agricultural practices, persisting hunger and malnutrition in several regions of the world.

Nothing new is being said when one appreciates that soil resources are precious in terms of their ability to address food security (quality and quantity), environmental quality and biodiversity and last but not the least human health and welfare. Although none of these three principles solely depends on soil, they are very much related to soil functioning (Romanya et al., 2006). Historically, humankind has neglected its soil resources more than once, often ending in the collapse of the dominant society and culture.

Understandably, the concept of soil quality (SQ) and its significance have been recognised since ancient times. Sensitivity to soil characteristics was evident in the cropping practices advocated by the ancient philosophers and cropping according to the character of the land was rule. Using senses of sight, taste, touch and smell, the philosophers set down qualitative guidelines for evaluating soil and its suitability to promote growth of a particular crop. The concept of SQ was formally initiated when Alexander (1971) suggested developing soil quality criteria in reference to the role of agriculture in environmental improvement. Soil quality needs to be ensured to facilitate better land use planning, because of the increasing number of

functions that the soil resources must either provide or accommodate (Karlen et al., 2003).

The concept of SQ is continuously evolving (Warkentin, 1995). In its current context, however, it is relatively new (Arshad and Coen, 1992; Doran and Parkin, 1994). To understand SQ as a modern concept, the complexity of soil and its functions have to be recognized. Soil should be recognized as a complex system of minerals, organic compounds, soil solution, soil gases and living organisms that interact continuously in response to natural and imposed biological, chemical and physical forces. In addition, soil should be accepted as a living system which represents a finite resource vital to life on earth (SSSA, 1995).

Various definitions of SQ are available in literature. More recently, SQ has been defined as the capacity of soil to function within land use and ecosystem boundaries, to sustain biological productivity, maintain environmental quality and promote plant, animal and human health (Carter et al., 1997; Karlen et al., 1998). As per Bouma et al. (1998), soil quality cannot be seen in isolation, but must be linked to certain types of land use and the associated management. In context of agriculture, SQ is a measure of soil's fitness to support crop growth without becoming degraded or otherwise harming the environment (Acton and Gregorich,1995). Soil quality is thus very important and significant concept with respect to agricultural production as well as its sustainability.

Soil quality assessment has been suggested as a tool for enhancing sustainability of soil and crop management practices. Hence, there is a need to develop criteria to evaluate soil quality and to take corrective measures to improve it. Assessing SQ is relatively difficult because unlike water and air quality for which established standards are available in the form of legislation, soil quality assessments are purpose- oriented and site-specific (Karlen et al., 1994). However, a quantitative assessment of soil quality could provide much needed information on the adequacy of the world's soil resource

Conventionally, a MDS of SQ indicators is developed based on expert knowledge of local soil conditions and soil-crop response. The relatively recent approach to development of MDS of SQ indicators involves the use of a statistical technique, namely, Principal Component Analysis (PCA). The PCA has been widely employed as an approach to acquire MDS for SQ assessment. Through PCA, the number of independent soil parameters could be reduced and the problem of multi-colinearity could be solved to some extent (Guilin et al., 2007). The PCA was employed as a data reduction tool to select the most appropriate indicators of site from the list of indicators generated in Pearson correlation coefficients method (Rezaei et al., 2006). Both the above mentioned approaches use physical, chemical and biological indicators. Further, land evaluation (LE) has also much to offer to the process of SQ assessment. Land evaluation is the assessment of performance of land for defined uses (Rossiter, 1996). The basic difference between SQ assessment and LE is that in the latter, we use only physical and chemical indicators (Rosa, 2003).

In general terms, the traditional land evaluation systems follow a Boolean or rule-based approach adapted to the principle of maximum limiting factors. There is a growing concern regarding failure of this method to incorporate the inexact or fuzzy nature of much of the land resource data. In recent years, there has been marked interest in the use of fuzzy modeling-based methodology (a mathematical approach) in land evaluation, and it can be considered as a new phase in the quantification trend. The use of strict Boolean algebra with a simple true/false logic in combination with a rigid, exact model is often inappropriate for land evaluation because of the continuous nature of soil variation, the uncertainties associated with describing the phenomenon itself or in the measurements made on it, or because of inexactness of much of the land resource data (Burrough, 1989; Chatterji, 2000).

Maintaining SQ at desirable level is a very complex issue due to involvement of climatic, soil, plant and human factors and their

interactions (Chaudhury et al., 2005). This issue is even more challenging in rainfed cotton growing environs of Maharashtra in view of various constraints viz., inadequate rainfall, shallow depth, sodicity, poor fertility and shrink swell nature of soils at many of the places. An yield gap of 840 kg/ha of cotton was reported in Maharashtra by Aggarwal et al. (2008). The physical constraints that limit cotton yield and result in its yield gap also include, among others, unsuitable soils. The yield of cotton has either reached a plateau or started declining in Maharashtra, one of the reasons for which could be soil constraints (Sadanshiv, 2010).

After the green revolution in wheat and rice during the late 1960s and early 1970s, if there is any other crop that has registered a phenomenal growth during the last 13-14 years, it is cotton. Cotton production in India has increased manifold, from 15.8 million bales in 2001-02, through 30.7 million bales in 2007-08 to 33.4 million bales in 2012-13 (Cotton Advisory Board, 2013). This has been primarily the result of introducing Bt (*Bacillus thuringiensis*) technology in cotton.

An agroecological region (AER) that comprises homogenous set of natural physical environments, such as climate, soils and physiography (landform) and often becomes a regional planning unit. The entire state of Maharashtra is categorized into four AERs, namely, AERs 6, 10, 12 and 19 (NBSS & LUP, 1992) that exhibit contrasting climate, soil and land use. Of these agroecological regions, 6 and 10 are the major cotton growing regions together accounting for 33.21 lakh ha (95.68 %) of the cotton area in Maharashtra (Anonymous, 2010). It would be interesting to study soil quality parameters in the two aforesaid cotton growing AERs that are dissimilar in terms of nature of soils, weather parameters and land use.

Agroecological subregion (AESR) 6.3 is the dominant cotton growing sub-region, a representative of AER 6 and similarly AESR 10.2 is the dominant cotton growing sub-region, a representative of AER 10. The discussion with respect to different aspects in the present study herein after would refer to AESRs instead of AERs.

Agroecological subregion (AESR) 6.3 is characterized by not, moist semi-arid ecosubregion with dry summers and mild winters whereas AESR 10.2 has hot, dry sub-humid ecosubregion with dry summers and mild winters. Soils of AESR 6.3 comprise gently sloping shallow Ustorthents grading to very gently sloping to nearly level Chromusterts and soils of AESR 10.2 are represented by soil great group associations of Ustochrepts- Chromusterts (Velayutham et al., 1999). The present study includes two districts, Akola district as a representative of AESR 6.3 and Nagpur district as a representative for AESR 10.2.

1.2 Importance of study

The study areas face a number of soil constraints namely, shallow depth, occasional drought, sodicity in AESR 6.3 and poor fertility, shrink-swell nature and narrow range of workable soil moisture in deep cracking clay soils in AESR 10.2. There is also growing threat from land degradation on cotton productivity and ecosystem sustainability. Despite this, only few studies have been carried out to assess the quality of soils of these regions. Even in these studies, SQ was not treated as an integrated concept in that only soil physical and chemical indicators were considered for evaluating SQ- biological indicators were ignored. The present study proposes to overcome this major limitation of earlier studies and presents results on a more sound and logical basis.

The baseline (reference) information obtained on various soil functions of the study area could be translated into a workable scale for farmers and land managers to identify whether a soil is being aggraded or degraded. The concept of Minimum datasets (MDS) refers to a set of specific soil measurements which is considered as a basic requirement for systematically assessing soil quality and has to be developed as region specific. The MDS constitutes mutually exclusive and locally relevant indicators. The use of MDS followed by its validation through correlation with sustainable yield index reduced redundancy of datasets and helped in enhancing the pragmatic value

of SQIs. Further, most of the researchers in the country have used only the MDS of physical and chemical SQ indicators. The MDS of microbiological indicators for assessing soil quality has, however, not been often recommended. The present study overcomes this limitation by also recommending MDS of biological soil indicators for the study area.

There is urgent need to adopt appropriate soil and crop management practices in these cotton growing subregions which would reduce soil degradation or maintain SQ at desirable level so as to sustain and enhance cotton productivity.

Keeping this in view, the present investigation entitled, "Soil quality assessment in rainfed cotton growing environs of two agroecological regions of Vidarbha, Maharashtra" has been undertaken with the following objectives.

1.3 Objectives of study

- To identify soil physical, chemical and biological indicators for rainfed cotton in selected agroecological regions.
- To develop an integrated soil quality index using conventional and mathematical approaches.
- To relate the soil quality index to crop productivity.

1.4 Scope and limitations

Scope

- Little research has gone into tracking the changes in soil characteristics over time. There is scope of monitoring change in physical, chemical and biological parameters of the selected soils over time.
- There is also scope of studying SQ changes as a function of management changes and also to relate it with crop productivity. In the present study, the SQ has been studied only under one set of farmer's management.

- Comparing the quality of soils growing Bt cotton with that of soils growing non Bt-cotton provides scope for yet another interesting study.

Limitations

- The present study on soil quality assessment gives scope to develop minimum dataset (MDS) of soil characteristics only. Rainfall, although is known to be highly relevant to growth of rainfed cotton, it could not, however, be included in developing MDS as it is not a soil parameter.
- If we had come across more number of sodic soils in the present study, then we could have assigned different weightages to sodic and non-sodic soils.
- Ideally, quality of the given soils should have been studied and compared under identical set of management conditions. However, it has not been possible to study soils under identical management as identification of farmers practicing identical management was difficult and beyond the scope of the study.
- Since one of the approaches applied to SQ assessment is through land evaluation (using fuzzy modelling) an attempt was, therefore, made to use this method for SQ assessment. However, this method is limiting in that it only involves evaluation of physical and chemical properties and does not include biological ones.
- Our understanding of the links between microbial diversity and soil functions is poor because we cannot measure easily the microbial diversity, even if we can detect unculturable microorganisms by molecular techniques.

CHAPTER - II

REVIEW OF LITERATURE

Lot of research has gone into soil quality, its assessment and monitoring. Our attempt in this chapter is aimed at presenting work reported on different aspects of soil quality by various researchers with a particular emphasis on those in two major cotton growing environs in Vidarbha region, Maharashtra namely, AESR 6.3 and AESR 10.2. The same is presented in the following four sections.

2.1 Soil Quality – Concept, Definition and Importance

2.2 Soil Quality Assessment Using Different Methods

2.3 Cotton Production in India – General Statistics and Constraint Analysis

2.4 Soil Quality of Cotton Growing Environs with Particular Reference to Vidarbha Region

2.1 Soil Quality – Concept, Definition and Importance

2.1.1 Concept of soil quality

As also discussed in Chapter I, namely, Introduction, the concept related to soil quality (SQ) is not new and has been articulated since ancient times (Carter et al.,1997). It is undergoing development in response to the idea that soils are part of land or terrestrial ecosystems. Thus, SQ brings together old and new ideas about soil and land. Roman philosophers stressed the value of soil and promoted agricultural practices, like the use of rotations that incorporate green manure or legumes, application of livestock manure to soil and fallowing to maintain natural soil fertility. Sensitivity to soil characteristics was evident in the cropping practices advocated by the ancient philosophers and cropping to the character of the land was a rule. Using senses of sight, taste, touch and smell, the philosophers set down qualitative guidelines for evaluating soil and its suitability to promote growth of a particular crop. Alexander (1971) formally initiated

concepts of SQ and suggested developing soil quality criteria in reference to role of agriculture in environmental improvement. Increasing concern over agriculture's impact on environment has created renewed interest on soil quality and soil health. In more recent years, due to concerns on soil degradation and the need for sustainable soil management in agroecosystems, there has been a renewed scientific attention to soil variables. Coupled with this is the idea of soil use which has emphasized the value of soil and soil properties for a specific function. Placing a value upon soil in regard to a specific function, purpose or use leads to the concept of SQ (Carter et al., 1997).

SQ has different meanings according to the perspective of the person. Depending on how the soil is used, quality may mean different things to different people. For example, in agricultural context, within which much of the discussion of soil quality has taken place, the farmer may think of SQ in terms of productive land that maintains or increases farm profitability as well as the conservation of farm resources so that future farming generations can make a living (Mausbach and Saybold, 1998). To the consumer, agricultural soil quality may mean a dependable supply of wholesome, affordable food and the protection of drinking water quality. To the environmentalist, it may be defined in terms of global nutrient cycling, water regulation, climate change and biodiversity. And for high level policy and decision makers, soil quality may be seen in terms of a nation's ability to stay competitive in the international market place and honor its international environmental commitments (Gregorich, 2006).

SQ is a holistic concept which recognizes soil as part of dynamic and diverse production system with biological, chemical and physical attributes. It is related to the concept of soil capability, which is as old as civilization itself. Although there has been an interest in soil and land quality from the beginning of agriculture, the SQ concept is continuously evolving (Warkentin, 1995). In its current context, however, it is relatively new (Arshad and Coen, 1992; Doran and

Parkin, 1994). As a concept, it differs from traditional technical approaches that focus solely on productive functions of soil (Swift, 1999; Sanchez et al., 2003).

SQ when considered as the capacity of a soil to function, specific functions of concern should be clear while applying the concept. Common examples of specific soil functions are, sustaining biological activity, diversity and productivity; regulating and partitioning water and solute flow; filtering, buffering, degrading, immobilizing, and detoxifying organic and inorganic materials including industrial and municipal by-products and atmospheric deposition; storing and cycling nutrients and other elements within the earth's biosphere and providing support of socioeconomic structures (i.e. buildings and roads) and protection for archeological treasures associated with human habitation. Soil quality integrates the physical, chemical and biological, components and processes of soil with its surroundings. Whether a research plot, field, watershed, or earth, soil functions within a larger system remain a key consideration in assessment of soil quality (NRCS, 2010).

Schjonning (2013) observed that the term SQ has mainly been used as a technical concept for grading soils. It is important that the values and goals in soil use planning and soil management are explicitly stated and related to the soil quality indicators. Such a cognitive SQ concept may facilitate the urgent need of soil scientists to interact with stakeholders in the society. Useful approaches for such exercises have been proposed in the literature.

2.1.2 Definition of SQ

Definition of SQ and selection of soil characteristics needed to quantify soil quality are still in the process of evolution, some of the much referred definitions of SQ are nevertheless reviewed hereunder.

In an agricultural context, SQ is usually defined in terms of agriculture productivity (e.g., a good quality soil produces abundant high quality crops), and specifically in regard to soil's capacity to

sustain and nurture plant growth. Although the basic idea behind SQ is fitness of soil for specific use, there is an on-going attempt to more rationally and elaborately define soil quality. Based mainly on definition of soil fertility introduced by Leopold (1949), Anderson and Gregorich (1984) were the first to define SQ as the sustained capability of soil to accept, store and recycle water, nutrients and energy. However, over the last decade, there has been a definite shift in the way agriculture is viewed. No longer is agriculture viewed as a closed operation, but rather as a part of a much broader ecological system, that interacts with, and affects, other various parts of the system.

Efforts to define soil health in the context of multiple soil functions were made initially by Warkentin and Fletcher in 1977 and were followed by more formalized definitions (Karlen et al.,1997), selection of indicators (Doran and Parkin, 1994) and specific strategies to enhance soil quality and soil health (Doran et al., 1996). Recent efforts to quantify soil health have resulted in the development of tools to evaluate the impact of management on the soil and environment. The soil quality test kit and soil health card are two such tools that provide users with a means to quickly evaluate soil properties and processes with minimal equipment and expertise.

SSSA (1987) defined SQ as inherent attributes of soil that are inferred from soil characteristics by indirect observations (e.g. Compatibility, erodibility and fertility). Larson and Pierce (1991) defined SQ as the capacity of a soil to function within the ecosystem boundaries and to interact positively with ecosystem. They also proposed a quantitative formula for assessing soil quality and suggested that such assessments could help determine how soils responded to various management practices. Arshad and Coen (1992) defined SQ as the sustaining capability of a soil to accept, store and recycle water, minerals and energy for production of crops at an optimum level while preserving a healthy environment. Karlen et al.

(1992) defined SQ as the ability of soil to serve as a natural medium for growth of plants that sustains human and animal lives.

Doran and Parkin (1994) defined SQ as capacity of a soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality and promote plant and animal health. Gregorich et al. (1994) defined SQ as a composite measure of both, ability of soil to function and how well it functions relative to specific use or the degree of fitness of a soil for a specific use. Gregorich and Acton (1995) defined SQ as soil's capacity or fitness to support crop growth without resulting in soil degradation or otherwise harming the environment.

A more detailed definition has been developed by the SSSA (1995) which states that SQ is the capacity of specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water or air quality, and support human health and habitation. Karlen et al. (1997) also defined SQ as the capacity of a specific kind of soil to function within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation. Bouma et al. (1998) also lent support to the definition of Karlen et al. (1997) by stating that SQ cannot be seen in isolation and must be linked to types of land use and the associated management.

Doran et al. (1996) defined SQ as the capacity of a soil to function within ecosystem and land use boundaries to sustain biological productivity, maintain environmental quality, and promote plant, animal and human health. Johnson et al. (1997) proposed that SQ is a measure of the condition of soil relative to the requirements of one or more species and to any human need or purpose.

There are various and sometimes conflicting definitions of SQ in the current literature. However, 'the capacity of soil to function' is the central idea in most of the definitions (Karlen et al.,1997). The term

SQ implies value judgment or degree of excellence of soil for a specific purpose (Schjonning et al., 2004). In addition to the intended use of a particular soil, the specific definition of SQ is dependent on its inherent capabilities (Andrews et al., 2004).

The SQ, soil health and soil condition are interchangeable as all describe the soil's ability to support crop growth without becoming degraded or otherwise harming the environment (More, 2010). Farmers prefer the term soil health because it reflects the judgments of the soil as either robust or ailing resource which is a holistic way to refer to soil. However, SQ is defined by the interactions of measurable physical, chemical and microbiological properties of particular soil. These properties can be managed and adjusted. SQ, therefore, should be distinguished from the inherent properties of the soil which can not be managed or adjusted by the farmer. Inherent properties can be determined by factors such as climate, topography, vegetation, parent material and time.

2.1.3 Importance of SQ

Descriptions of SQ reflect appreciation for soils fitness for use (Larson and Pierce, 1994) and capacity of soil to resist and recover from degradation (Blum, 1998; Greenland and Szabolocs, 1994). SQ concept since its inception has been strongly associated with efforts to address agricultural sustainability (Youngberg, 1992; Parr et al., 1992; Warkentin 1995; Wander et al., 2002). General definitions for SQ, which are understandably broad, emphasize the capacity of soil to perform services including the production of plants and animals and the transport and regulation of matter (water and other compounds) present in or added to soils (Doran and Parkin, 1994; Karlen et al., 1998).

Soil quality is increasingly proposed as an integrative indicator of environmental quality (National Research Council, 1993; Monreal et al., 1998), food security (Lal, 1999) and economic viability (Hillel, 1991). Therefore, it would appear to be an ideal indicator of sustainable

land management. Soil is the foundation for nearly all land uses. It is no coincidence that definitions of soil quality and sustainable agriculture are parallel. SSSA (1997) defined soil quality as, "the capacity of a specific kind of soil to function within natural or managed ecosystem boundaries, to sustain biological productivity, maintain environmental quality, and promote plant and animal health", a definition which in itself underlines the importance of SQ. Another organization (Technical Advisory Committee, 1988 to the CGIAR) has suggested that, sustainable agriculture should involve successful management of resources to satisfy changing human needs while maintaining or enhancing the quality of the environment and conserving natural resources. By reflecting the basic capacity of the soil to function, soil quality integrates across many potential uses. Despite its clear utility, soil quality has not been widely adopted as an indicator of sustainable land management (Herrick, 2000).

Rao (2007) opined that SQ or what is popularly called as soil health is a fundamental consideration in maintaining the vital soil functions and ensuring agricultural and environmental sustainability. Soil ecosystems remain firmly at the foundations of human life support systems, but are the least understood among the natural ecosystems, and are also increasingly among the most degraded. Soil erosion, loss of soil organic matter and nutrient depletion are among the leading contributors to impaired soil health, reduced crop yields and poverty in the developing world. Global warming will further exacerbate this problem. Not surprisingly, therefore, soil health tops a list of priorities of UN Millennium Project's hunger task force.

Soil quality and its protection is one of the main contemporary preoccupations and ecologic problems, rivaled only by the climatic change and their impact or by biodiversity protection (Carstea, 2000). More (2010) observed that the term 'soil quality' is gaining popularity in the agriculture sector, especially as farmers are striving hard to sustain crop production and maintain soil health.

With increasing demographic pressure, intensive land use and improper management, soils have been subjected to severe degradation, leading to deterioration in its quality. In the developing countries like India, a large proportion of the land area shows clear evidence of advanced and continuing degradation seriously affecting the country's productive resource base (Abrol and Sehgal, 1994). Despite growing threat from land degradation on crop productivity and ecosystem sustainability, few studies have been carried out to develop methods for evaluating and monitoring soil quality (Kundu et al., 2012).

2.2 Soil Quality Assessment

SQ has historically been equated with agricultural productivity. Soil conservation practice to maintain soil productivity is as old as agriculture itself, dating back to the Roman Empire (Jenny, 1961). The Storie Index (Storie, 1932, 1964) and USDA Land Capability Classification (Klingebiel and Montgomery, 1973) were developed to separate soils into different capability classes. Soil capability was employed by farmers for land purchase and management and also by government agencies for tax appraisal. Later, soil productivity ratings were developed to help farmers select crops and management practices that would maximize production and minimize soil erosion or other adverse environmental effects (Huddleston, 1984). These rating systems were the important predecessors of recent attempts to quantitatively assess SQ.

The assessment of SQ, as we understand from the preceding sections, is an important activity, anticipated to increase in importance as we become more aware of the need to protect and preserve soil and its ability to sustain its functions. A useful framework to assess/ evaluate SQ is based on the following sequence: functions, processes, attributes or properties, attribute indicators, and methodology. Generally, attributes describe a critical soil property involved with the process or processes underlying a function. The attribute, or soil property, is most useful when it reflects or measures change in the process. In many cases, the specific property may be difficult to

measure directly, so an indicator (an associative property; i.e., a surrogate or proxy) or pedotransfer function (Bouma, 1989) can be used to serve as an indirect, practical measure of the attribute. Once attributes of the soil that can serve as indicators of SQ have been selected, it is essential to ensure that standard methods of sampling, pretreatment and analysis are selected appropriate to this evaluation (Nortcliff, 2002).

2.2.1 SQ indicators

There are many soil attributes encompassing a broad range of soil physical, chemical and biological properties that can be used to assess the quality of soils. It is important to recognize that soil quality indicators are limited to properties impacted by soil management only and do not include inherent soil characteristics. Although it is useful to examine these properties individually, soil should be viewed as an integrated system rather than as a collection of separate parts or processes. For example, physical and chemical properties are shaped by biological activity, and biological activity is enhanced or limited by chemical and physical conditions. As soils perform many simultaneous functions, the goal of relating indicator properties to specific functions or processes is very difficult, if not impossible (Rao and Manna, 2005).

Indicators can represent a single attribute or a set of attributes. It is generally acknowledged that indicators should be easily measured and verifiable, have some sensitivity to variations in soil management and have a relatively low sampling error. Indicators that have a relatively long record of sampling or are found in historical records are of particular use. The choice of indicator is based on the provision of available methodology, including ease of duplication and facility for accuracy and speed (Gregorich and Carter, 1997).

Soil quality indicators that are reliable, reproducible and capable of detecting change in soil physical, chemical and biological properties, processes and their interactions should be selected. They must be qualitative or semi-quantitative for immediate use by farmers or land

managers, and quantitative for the people responsible for developing the long – range process based strategies that will improve land use, enhance plant, animal and human health and sustain biological diversity within natural and fabricated ecosystems. It should be a component of exciting data base, integrate soil physical, chemical and biological processes/factors, easy to capture and interpret, encompass ecosystem processes and related to process oriented modeling, accessible to many users and applicable to field conditions, sensitive to variation in climate and management, easily measurable and measurements should be reproducible (Doran and Parkin, 1994; Gregorich et al.,1994).

SQ evaluation typically includes the quantification of indicators that are derived from educational studies or general quantitative observations of soil (Saybold et al.,1998).

Physical indicators

Physical indicators are related to arrangement of solid particles and pores. Examples include depth of top soil, bulk density, porosity, aggregate stability, texture, crusting and compaction. Physical indicators primarily reflect limitations to root growth, seedling emergence, infiltration, or movement of water within the soil profile. Physical properties of crop affect performance in many ways; plant health and growth are heavily influenced by the soils, texture, bulk density, porosity, water holding capacity and the presence or absence of hard pans. These properties are all improved through additions of organic matter to the soil. Soil physical properties also influence the soil water and plant water relationships. The portioning of water at soil surface is important because it determines both the quality and quantity of surface and ground water as well as the amount of water that will be available for plant growth. Water running over the surface, rather than infiltrating it, can carry sediments and other pollutants (Karlen et al., 1997). Soil depth is an easily measurable and independent property that provides direct information about a soil's ability to support plants. Effective soil depth is the depth available for roots to explore for water

and nutrients. Layers that restrict root growth or water movement include hard rocks, naturally dense soil layers such as fragipans, petroferric and petrocalcic horizons, duripans and human induced layer of high bulk density such as plow pans and traffic pans (Singh and Ghosh, 2009). Determination of physical indicators of SQ is a greater challenge than determining other SQ indicators. The basic problem is that the soil physical properties vary widely in time and space, and are interdependent. It is difficult to establish critical level of each property in isolation.

Chemical indicators

Soil fertility, nutrient restoring and recycling, and environmental quality issues are directly related to chemical indicators. These include soil organic matter, pH, electrical conductivity, and extractable N, P and K. Soil organic matter (SOM) includes a number of fractions such as light fraction, microbial biomass, water soluble organics and humus. Soil organic matter (SOM) is the mainstay of soil quality. As a general rule, declining yield trends have been attributed to reduction in SOC levels by many researchers. SOM is a very useful indicator because it interacts with numerous other soil components which affect many soil properties like water retention, aggregate formation, bulk density, infiltration and aeration, pH, buffering capacity, cation exchange property, mineralization, sorption of pesticides and other agrochemicals and activity of soil organisms. Soil pH also indicates the solubility of most chemical elements in soils and their associated availability, deficiency, or toxicity to plant growth. At low pH, Al and Mn become more toxic to plants. Solubility of most micronutrients except for Mo decreases as pH increases, and deficiency symptoms are often seen when pH is greater than 7. The adverse impact of high pH and sodicity on physical properties and nutrient availability is well known. Soil pH has also significant impact on soil microbial and mineralization processes. CEC is highly related to clay content and the amount of organic matter content in soil. The pH dependent CEC of acid soils increases slowly with pH from 3 to 5 and rather rapidly afterwards, and

soil organic matter is the major contributor to pH dependent CEC (Rao and Manna, 2005).

In long-term fertilizer experiments in India, Manna et al. (2004) reported that SOC decline is the general cause of reducing yield trends in the initial years. However, as a result of continuous cropping with fertilizers or fertilizers + FYM, there was a subsequent build up of soil carbon which reduced the extent of negative yield trends but did not, however, result in restoration of the original yields.

Biological indicators

SQ determination also involves many biological attributes (Singh and Ghosh, 2009). Soil biological attributes are early warners of soil degradation and they are good indicators for comparing the relative performance of different soil management practices and aggrading/degrading soil quality. Biological soil health can be measured from the biological indicators. Soil biochemical properties are potential indicators of soil quality. The dynamic nature of soil microorganisms and their sensitivity to various agricultural management practices make them early indicators of soil quality. Agricultural practices affect many biological properties. The changes in these properties can be used to evaluate the impact of agricultural practices on soil quality (Tomar et al., 2009).

Biological indicators include measurement of micro and macro organisms, their activity or byproducts. The soil ecosystem has a diverse population of organisms, ranging from beneficial to harmful ones. Most of the SQ definitions, however, focus on the presence of beneficial rather than the absence of detrimental organisms, although both are critically important (Singh and Ghosh, 2009). The organisms contribute to the maintenance of SQ in that they control the decomposition of plant and animal materials, biogeochemical cycling including nitrogen fixation, the formation of soil structure and the fate of organics applied to soils. Various measures of viability of microbial

community have been suggested as measures of SQ indices (Rao, 2007).

A large, diverse, and active population of soil organisms may be the most important indicator of a healthy, high-quality soil. Yet, soil biological activity may be the most difficult indicator to satisfactorily measure and interpret. A high quality soil is biologically active containing a wide diversity of microorganisms. However, diversity is so little understood, less than 1 percent of the microorganisms have been actually isolated and identified. A good ecological indicator should also show prompt and accurate response to an external perturbation, reflect some aspect of the functioning of the ecosystem, be readily and economically accessible and be universal in distribution and yet show individual specificity to temporal or spatial variations in the environment. Such a stringent requirement coupled with a poor understanding of diversity-function relationships has meant that we have made very little progress in identifying such indicators. This situation is unlikely to change in the near future. Therefore, for a working definition of soil biological quality and ease of analysis, biologically active fractions of SOM and biochemical attributes of soil have proven more useful (Rao and Manna, 2005).

Several authors have emphasized the use of biological factor as indicators of soil quality which often equate soil quality with relatively dynamic properties such as microbial biomass, microbial respiration, organic matter (OM) content, particulate organic matter (POM) content, organic matter mineralization and denitrification (Karlen et al., 1992; Visser and Parkinson, 1992; Boehn and Anderson, 1997; Franzluebbers and Arshad, 1997) or soil microbial C, phospholipids, and soil enzymes (Franzluebbers et al.,1995; Kennedy and Papendick, 1995; Gregorich et al.,1997) or total organic C and N (Karlen et al., 1992; Gregorich et al., 1997). Waksman (1927), who studied importance of soil microorganisms from the view point of soil fertility, stressed that besides physical and chemical factors, soil biology was most needed property to predict soil fertility.

Particulate organic matter (POM, >53mm) represents a significant proportion of the slow pool of SOM and is important in maintaining the stability of macroaggregates (>250mm). POM and microbial biomass are considered as biologically active fractions of SOM and are sensitive indicators of management-induced changes in the fate of crop residues and the turnover of SOM constituents. They have been found to predict the direction and rate of change of soil quality earlier and better than other indicators. Soil respiration and nitrogen mineralisation are widely used as indices of biological activity. Decrease of microbial biomass carbon as a fraction of total organic carbon implies a reduction in microbial transformation and intensity. The metabolic quotient or qCO2 is a more sensitive indicator of soil microbial reaction to cropping systems, lower values implying more stable and mature systems where carbon utilization efficiency of the microbial population is higher due to shift from zymogenous to autochthonous microflora. Dehydrogenase activity has been widely used as a generalized comparative index of microbial activity but it has not always been consistently correlated with microbial activity (Rao and Manna, 2005).

The populations of meso and macro-fauna in soils have also been considered as a part of quality definition (Berry, 1994). One could choose to use presence or absence of a particular species as a measure of soil quality. Measuring soil fauna population involves decision about which organisms to measure and how to measure them. For example, in measuring earthworm population, (the size of which is frequently mentioned as an important measure of soil quality) measurement choices include number of organisms per volume or weight of soil, number of species or a combination of number of organisms and species. Reganold and Palmer (1995) used total earthworm population per square meter, total earthworm weight and average individual earthworm weight as biological indicators of soil quality.

Visual indicators

More (2010) identified visual SQ indicators in addition to the physical, chemical and biological ones which are properties, processes and characteristics that can be measured to monitor changes in the soil. It may be worth mentioning here that these visual indicators may be obtained from observations or photographic interpretations. Exposure of subsoil, change in soil colour, ephemeral gullies, ponding runoff, plant response, weed species, blowing soil and deposition are few examples of potential locally determined indicators. Visual evidence, he opined, could be a clear indication that SQ is threatened or changing. He also opined that SQ indicators are important to i) focus conservation efforts on marinating and improving the condition of soil; ii) evaluate soil management practices and techniques; iii) relate SQ to that of other resources, iv) collect the necessary information to determine trends; v) determine trends in the health of soils and vi) guide land manager decisions.

Use of Minimum datasets of SQ indicators

Often SQ evaluation methods use a number of parameters (SQ indicators) that are neither mutually exclusive nor locally relevant and hence fail to produce results that are of pragmatic importance. There arises a need of identifying a minimum dataset i.e. a MDS of SQ indicators to enable assess SQ appropriately, effectively and meaningfully. In concept, the development of MDSs involves selection of a small subset of attributes that will comprise locally relevant indicators and be exclusive. Over the last several years, researchers have tried to establish minimum data sets of physical, chemical and biological indicators for SQ assessment.

One of the major challenges recognized is to decide how many and which of the soil parameters measured should be included in the assessment. The selection of soil parameters to assess SQ is substantially crucial because the outcomes will have little meaning if the parameters are not selected rigorously. Theoretically, each of the

large number of physical, chemical and/or biological soil parameters may potentially be for assessing the site-specific SQ. Concerning the changeability of land-use forms, the spatio-temporal variability of soil, the high cost of comprehensive data accessibility, the colinearity of soil parameters and so on, it is however, necessary to develop a minimum data set (MDS) in which the selected parameters can maximally cover the information. Using a minimum data set (MDS) reduces the need for determining a large number of indicators to assess SQ (Govaerts et al, 2006).

Mechanisms to measure changes in SQ are important if soil scientists are to develop better methods (which will provide understanding) to manage the soil/crop system. The MDS is developed through various approaches, including, among others, using expert knowledge, correlation and Principal Component Analysis (PCA) and remote sensing techniques which are discussed below.

2.2.2 Conventional approach

Storie (1964) considered that the productivity of the land is the function of soil, climate and vegetative properties. In this system, nine properties have been used in storie index rating (SIR) because incorporation of other factors makes the system un-yielding. The nine factors are soil morphology (A), surface texture (B), slope (C) and six variables (Xi) that rate drainage class, sodicity, acidity, erosion, micro relief and fertility from 1% to 100%. These are converted to values and multiplied together. SIR is determined as per the following equation

$$SIR = [A \times B \times C \times \sum_{i=1}^{6} Xi \,] \times 100$$

Pierce et al. (1983) developed productivity index (PI) with a view to evaluate productivity of soil in top 100 cm, specially with reference to potential productivity loss due to soil erosion. The rating of PI model is based on the sufficiency for root growth which depends on potential available water storage capacity, bulk density, aeration, pH, and EC. A value from zero to one is for each property describe the relative importance of that parameter for root development.

Parr et al. (1992) were first to propose a SQ index (SQ) at the International Conference on the Assessment and Monitoring of soil quality held at the Rodale Institute, United States, the equation to determine it being $SQ = f(SP, P,E,H, ER,BD, FQ, MI)$, where, SP denotes soil properties, P denotes potential productivity, E the environmental factors, H the health (human/animal), ER the erodibility, BD the biological diversity, FQ the food quality/safety and MI are management inputs.

Singh et al. (1992) developed a soil tilth index that is based on using five physical soil properties such as bulk density, cone penetration index, aggregate size uniformity coefficient, organic matter and plastic index. This index is a multiplicative combination of the tilth coefficients and it could be expanded to include other soil attributes such as soil chemical and biological properties. These indices could be used to monitor and predict the effect of farming systems and management practices on SQ or could provide early warning of soil degradation/aggradation/sustainability.

Karlen et al. (1994) were first to establish multi-parametric index for SQ. This framework uses selected soil functions, which are weighted and integrated according to the following expression as

$$SQ = q_{we}(wt) + q_{wma}(wt) + q_{rd}(wt) + q_{fqp}(wt),$$

where, q_{we} is the rating for the soil's ability to accommodate water entry; q_{wma} is the rating for the soil's ability to facilitate water transfer and absorption, q_{rd} is the rating for the soil's ability to resist degradation, q_{fqp} is the rating for the soil's ability to sustain plant growth, and wt is the numerical weight for each soil function. Thus, overall SQ score is given by the sum of all function scores.

Doran and Parkin (1994) described a performance-based index of SQ that could be used to provide an evaluation of soil function with regard to the major issues of sustainable production, environmental quality, and human and animal health. They proposed the following SQ index consisting of six elements.

$$SQ = f(SQE1, SQE2, SQE3, SQE4, SQE5, SQE6),$$

where SQE1 is the food and fibre production, SQE2 the erosivity, SQE3 the ground water quality, SQE4 the surface water quality, SQE5 the air quality, and SQE6 is the food quality. The advantage of this approach is that soil functions can be assessed based on specific performance criteria established for each element for a given ecosystem.

Roming et al. (1997) developed SQ based on farmer's perception, a score card was developed for assessing quality on a rating scale of healthy, impaired and unhealthy soil based on sensory observations such as look, feel and smell.

Wang and Gong (1998) analysed SQ changes after eleven years of reclamation in subtropical China. This study was conducted at the Qian-Yan-Zhou experimental station of the Chinese Academy of Sciences (QYZES) and soils are classified into four soil groups namely, red soils, paddy soils (PS), meadow soils (MS), and umbrihumus meadow soils (US). They divided each of the indicators into four classes I, II, III, IV. Class I is the most suitable for plant growth, class II suitable to plant growth but with slight limitations, class III with more serious limitation than class II, and class IV with severe limitations for plant growth. For judging the SQI value of any site against maximum theoretical value, they combined 12 indicators into relative soil quality index (RSQI). The equation for calculating RSQI value is

$$RSQI = (SQI / SQI_m) \times 100,$$

where SQI is SQ index, SQI_m is the maximum value of SQI. The SQI is calculated from the equation as $SQI = \sum Wi\ li$ where, W are the weight i^{th} of the indicator, I the mark of the i^{th} indicator class. By computing RSQI values, SQ in different regions can be compared even if they are evaluated with different evaluation systems, weightings, and classes.

Pettapiece et al. (1998) estimated the change in SQ for 15 eco-districts in Alberta, Canada. These changes were estimated from the change in ratings over 30 years, which were based on EPIC

simulations of soil processes. This approach primarily reflects goals related to crop productivity, but it also provides direct estimates of the type and extent of soil degradation, which could be used to develop indicators for other goals related to soil functions. SQ assessment typically includes the quantification of indicators that are derived from educational studies or general quantitative observations of soil (Saybold et al., 1998).

Hussain et al. (1999) studied adaptation of SQ indices and application to three tillage systems in southern Illinois having silty loam nature of soil. To quantify the effects of the three tillage systems on SQ and to test the sensitivity of various indexing procedures, they developed five different variations by modifying the weighting factors used for the various individual indicators. The general description for all indices was as water relations = f(x aggregate stability + x organic C + x surface residue + x porosity); nutrient relations = f(x organic C +x water storage porosity + x Bray P + x exch K + x soil pH); rooting relations = f(x bulk density + x soil pH + x organic C+ x air porosity), where x = weighting factor. Hence the overall SQ index was computed using the equation as Index = f (y nutrient+ y water+ y rooting), where, y = weighting factor for each function. To complete the evaluation, the six overall SQ indices and the individual function ratings were compared using ANOVA and individual function ratings were regressed against the dependent variables (erosion, yield, and plant population).

Bindraban et al. (2000) revealed that land quality indicators should represent a generic description of the functional role of land. System approaches that integrate relevant factors and processes e.g. in models, are a valuable means to derive land quality indicators.

Many potential parameters of SQ assessed at various scales have been proposed (Karlen et al., 2001). For example, a SQ index was estimated by weighing factors related to water infiltration (aggregate stability, microbial processes), soil pH, and plant growth (rooting depth, water relations and nutrient relations) (Karlen et al.,

1994). However, Karlen et al. (2001) stated that there is no ideal or universal index for SQ.

Bremer and Ellert (2004) provided examples of the development and use of SQ indices. They noted that the first publication related to SQ assessment addressed the use of a soil productivity rating system, like the Storie Index Rating. This system aggregates variables controlling yield by the use of multiplication, addition, or a combination of the two. The Storie Index Rating is calculated by multiplying separate ratings for profile morphology, surface soil texture or soil slope, by modifying factors namely, soil depth, drainage or alkalinity. Elaboration of soil productivity ratings is carried out by four steps viz, (i) Assignment of numerical values to soil properties, landscape characteristics, and weather conditions that influence plant growth and yield; ii) use of both additive and multiplicative processes to formulate factor ratings and combine factors into final productivity ratings; iii) use of available yield data (either directly or indirectly) to develop and validate the ratings and iv) precision specification of all criteria used to assign numerical values, derive factor ratings, and combine factors in the model.

In another example, Bremer and Ellert (2004) considered soil assessment with the aim of estimating sufficiency of soil conditions for root growth. In particular, soil productivity index (Pierce et al., 1983) is defined as a combination of sufficiency of available water holding capacity, bulk density, and pH.

Bremer and Ellert (2004) indicated that since the early 1990s, there has been considerable effort to develop soil ratings based on measured soil properties for the comparison of soil management systems (Karlen et al., 2001; Letey et al., 2003). In this approach, SQ is considered an inherent property of soil that can be determined from ascertainable soil attributes (Larson and Pierce, 1994). When a SQ parameter declines below an acceptable limit, an appropriate management response is required to increase SQ. Acceptable limits

depend on land use, soil characteristics, landform, and climatic conditions.

Masto et al. (2005) calculated the SQ Index without the weighing factors. They observed that weighing factors did not affect the relative ranks of individual treatments.

Kundu et al. (2012) assessed soil health of Vertisols of AESR 10.1 using selected physical, chemical and biological attributes of soils from Sehore and Vidisha district of Madhya Pradesh. The evaluation was done using 15 soil attributes comprising physical (available moisture, texture and bulk density), chemical (pH, available N, P, K, S, Fe, Mn, Zn, Cu and B) and biological (soil organic carbon and microbial biomass carbon).They assigned weight to each attribute depending on available knowledge about their relative role in influencing crop yield and also on the basis of soil conditions, cropping pattern and agro-climatic conditions of study area. They categorized the status of each attribute into four classes namely, Class I (Very good), Class II (Good), Class III (Poor) and Class IV (Very poor) with assigned marks of 4,3,2 and 1 respectively. SQ index was calculated by the relationship $SQI = \sum Wi\ Mi$, where, Wi = weight of i^{th} indicator and Mi = marks of i^{th} indicator class. The theoretical range of SQI was 100 to 400 i.e. minimum value is 100 (poor quality soil) and maximum value is 400 (best quality). Then for judging the SQI value of any site against maximum theoretical value, they computed relative SQ index (RSQI) as $RSQI = \frac{SQI\ of\ the\ given\ site}{Maximum\ theorotical\ value\ of\ SQI} x\ 100$

Using this RSQI, they categorized soils with RSQI values of less than 50% as poor, 50-70% as medium and more than 70% as good quality soil.

2.2.3 Mathematical approach

Diack and Stott (2001) developed a SQ index for Chalmers silty clay loam soil. The study was conducted in a long-term (16 yr) experiment (integrated pest management) field, located at the Agronomy Research Center at Purdue University, West Lafayette IN.

They developed the model and rating of quality, used following approach for initiating the development of a SQ index. They first set goals for high quality soil and subsequently set criteria for high quality soil in order to determine SQ indices. The rank criteria were set according to goals and definition of SQ, weight given to each parameter according to the rank of criteria, all weighted parameters added to obtain a numerical value for a given soil. The model has been modified as follows: $Q = q_{we}w_{we} + q_{wt}\, w_{wt} + q_{rpd}\, w_{rpd} + q_{rbd}\, w_{rbd} + q_{spg}\, w_{spg}$, where Q is the SQ, q_{we} is the rating for accommodating water quality (final infiltration rate), q_{wt} is the rating for water transport and absorption (bulk density and soil penetrability), q_{rpd} is the rating for resisting physical degradation (sealing index), q_{rbd} is the rating for resisting biochemical degradation (total organic carbon, particulate organic carbon, dissolved organic carbon, microbial biomass carbon, enzyme activity, q_{spg} is the rating for sustaining plant growth (total N) and *w* is the weighing factor for each function.

Mohanty et al. (2007) studied SQ effects of tillage and residue under rice–wheat cropping on a Vertisol in India. They developed SQI by regressing bulk density (BD), penetration resistance (PR), water stable aggregates (WSA) and soil organic matter (SOM) on crop yield. They delivered a linear regression of crop yield on each soil property as Y = a + bX, where Y is the grain yield of the crop, X the soil property and 'a' and 'b' are the constants. The proportion of R^2 variation obtained from the regression of soil measurements on yield was used to weight each soil property score. The overall SQ index for the 15-cm surface layer of this Vertisol was calculated by summing weighted scores for each function as $SQI = \sum wf_i\, x_i$ (for i = 1 to n), where SQI is the SQ index, wf_i the weighted score of the coefficient of determination obtained from the linear regression of the selected property Xi on yield and n is the number of properties. So, the combined SQI for the rice–wheat system was calculated using equation SQIc = α SQIr + (1- α) SQIw, where, SQIc are SQI values for the rice– wheat system, SQIr for rice and SQIw for wheat, α is a

constant that could be calculated in such a way that it gives minimum variance. The combined equation was written as $SQIc = [V_1/V_1+V_2]$ $SQIr + [V_2/V_1+V_2]$ SQI_w, where, V_1 and V_2 are variance of SQIr and SQIw respectively.

While evaluation of SQ has been the objective of many field experiments, the results of these extensive investigations have not reduced the complexity of this subject. These studies have not attempted to quantify SQ as a degree or grade of perfection. An effective remedy which would account for the complexity and allow for evaluation of SQ as a degree or grade of perfection is the fuzzy multi-attributive approach.

It is well known that SQ evaluation has not been fully quantified, as evidenced by the ongoing debate in scientific literature. The uncertainty that is inherent in any evaluation process involves both data and model ambiguity; this ambiguity includes measurement error, inherent soil variability, soil instability, conceptual ambiguity, over – abstraction or even simple ignorance of key factors that can impact SQ. Due to the wide range of factors that make up SQ and its inherent uncertainty, we believe that a unique approach must be taken to address SQ. It was proposed that randomness and uncertainty of SQ be dealt with by using fuzzy modeling (Jager, 1995; Pedrycz and Gomide, 1998; Ross, 1995). This approach provides the basis for analysis of systems characterised by a high degree of uncertainty, nonlinearly and complexity.

The concept of fuzzy modelling is a generalization of conventional set theory; the concept of belongingness to a set has been modified to include partial degrees of membership i.e. values along the continuum between 0 and 1, encoded as a fuzzy membership function (MF). An MF is the central concept of the fuzzy set theory, where MF represents the relationship of an element to a set. An MF of a fuzzy set is expressed on a continuous scale from 1 (full membership) to 0 (full non-membership).

Not much use of fuzzy modeling has, however, been made in SQ assessment. Torbert et al. (2008) studied on SQ assessment using fuzzy modeling for a crop field located in Bell County, TX, USA, on the Elm Creek Watershed. The soils within this study site were a Heiden clay (fine, montmorillonitic, thermic Udic Chromusterts), a Houston black clay (fine, montmorillonitic, thermic Udic Pellusterts), and a Ferris clay (fine, montmorillonitic, thermic Udorthertic Chromusterts). They developed the concept of a fuzzy SQ indicator (FSQI). Instead of using the common definitions of SQ indicators such as 'physical, chemical, and biological properties, processes, and characteristics of soil' that can be measured to monitor changes in the soil. The application of FMA (Fuzzy Modelling Analysis) is a two step process. The first step requires the selection of the various IFSQIs to be utilized and to define the membership functions for all of these IFSQIs. In the second step, parameters of the membership functions have to be defined with suitable SQ concepts. In this example, soil total P and soil organic C values taken at the study site were employed.

FSQI shows the degree of perfection/excellence of soil. In particular, two general types of FSQIs were defined as the individual fuzzy SQ indicator (IFSQI) type and the combined fuzzy SQ indicator (CFSQI) type. The IFSQI is considered to be an index of quality for the *j* soil attribute that takes into account the specifics of the *l* user group and the *k* aspect of data quality evaluation. The IFSQI is defined as a number in the range from 0 to 1, which reflects an estimation given by an expert in accordance with SQ concepts, and modeled by an appropriate membership function.

Alternative approach to SQ assessment by using fuzzymodelling was adopted by Burrough (1989); Chatterji (2000) and Chatterji et al. (2002) through 'land evaluation' using fuzzy modeling. They concluded that Fuzzy-set methodology is a refinement of Boolean logic, which has only two possibilities of membership: full (MF value 1) or none (MF value 0). They assigned a membership value ($0.0 < MF < 1.0$) to a parameter depending on their degree of closeness to a particular class.

Soil characteristics, which are given in classes, are converted to a grade of membership, depending on the values of the characteristics. Standard indices (Xi) for the MDS components were finalised on the basis of their point/range values in the highly suitable class and knowledge of experts on the soils in relation to the crop. Ranking was assigned to each parameter based on the relative importance of that parameter to the cultivation of the cotton crop and was based on local experts' knowledge and available literature and the weightages were derived. On a 0~1 scale, any parameter having a membership of 1 (highly suitable class) in any land unit suggests that the parameter has the complete belongingness to a particular class. The joint membership functions (JMFs) is a sum of the product of MF and weightage. The composite soil index (CSI) of a SQ parameter is the average of the aggregated JMF values of the parameters for a particular pedon which conceptuallly and for all practical purposes holds the same implication as that by SQI.

2.2.4 Principal Component Analysis (PCA) based method

PCA in particular, has been widely employed to acquire MDS for SQ assessment. Through PCA analysis, the number of independent soil parameters could be reduced and the problem of multi-colinearity could be solved to some extent. In many cases, however, reducing the number of soil parameters for finally assessing SQ means the loss of information represented by those reduced parameters (Guilin et al., 2007).

The MDSs often include many auto-correlated properties, are tedious and costly to collect, and sometimes are not specific to assessment of various land use systems. In such cases, Pearson correlation coefficients could be used to determine the eligible dependent variables for inclusion. Then Principal Component Analysis (PCA) is employed as a data reduction tool to select the most appropriate indicators from the list of indicators generated in Pearson correlation methods. Those soil properties that did not show a strong

relationship i.e. a Pearson correlation coefficient <0.50, were eliminated from the data list (Rezaei et al., 2006).

Andrews and Carroll (2000) were first to develop a general approach for choosing the most representative indicators from large existing data sets and used for a poultry-litter management case study at Institute of Ecology, University of Georgia, Athens, Georgia, USA to illustrate the design and use of SQI. A multivariate statistical technique was used to determine the smallest set of chemical, physical, and biological indicators that account for at least 85% of the variability in the total data set. They defined this set as the minimum data set (MDS) for evaluating SQ. The efficacy of the chosen MDS was then evaluated to assess sustainable management by performing multiple regressions of each MDS against numerical estimates of environmental and agricultural management sustainability goals (i.e., net revenues, P runoff potential, metal contamination, and amount of litter disposed of). Each MDS was then transferred and combined into an additive SQI. Index values exhibited significant differences between management treatments. Use of this generalized framework allowed indices to be tailored to local conditions. The resulting SQ index appeared to be an effective monitor of sustainable management.

Andrews et al. (2002[a]) compared SQ indexing methods for vegetable production systems in Northern California under varied soils namely, Reiff loams (coarse loamy, mixed, nonacid, Thermic Mollic Xerofluvents) and Yolo silt loams (fine-silty, mixed, nonacid, Thermic Typic Xerothents). They compared the most common method of MDS selection, expert opinion (EO), with the use of a multivariate data reduction technique and standardized principal components analysis (PCA). They chose minimum data set from the available data according to consensus of the project investigators and common management concerns in the Sacramento Valley. They retained only the highly weighted variables from each PC for the MDS. After that multiple regressions of both the EO and PCA-MDSs were performed using management goal variables as the dependent variables. After

determining the variables for the MDS, they transformed every observation of each MDS indicator for inclusion in the SQI methods. The three SQ indices were compared: an additive SQI (ADD SQI); a weighted, additive SQI (WTD SQI); and a hierarchical decision support system (DSS SQI). Like the other SQIs, the DSS used scored indicator values from either the PCA or EO selected MDSs. The DSS SQI treatments means and standard deviations were then calculated. Index outcomes were compared to the original data in two ways, to understand the driving mechanisms and as a validation attempt. A Varimax rotation of the standardized PCA using all significant soil indicators was also performed. Then an ANOVA was calculated using the rotated scores from Varimax PC to compare treatment mean. This result was then compared with the SQI results by using Pearson correlation coefficients.

Andrews et al. (2002[b]) constructed SQI for on-farm assessment in California's Central Valley. The three main steps of this technique were selection of minimum data set (MDS) of indicators that best represent soil function followed by scoring the MDS indicators based on their performance of soil functions and followed by integration of the indicator scores into a comparative index of SQ using the following relationship $SQI = \sum_{i=1}^{n}(Wi \times Si)$ where, W is the PC weighting factor and S is the indicator score. They compared the calculated SQI treatment means using ANOVA and Student's t at $\alpha = 0.10$. They assumed that higher index scores meant better SQ or greater performance of soil functions.

Chaudhury et al. (2005) determined the SQ index of the soil of experimental site belonging to New Gangetic Alluvium with sandy loam texture at Central Research Institute for Jute and Allied Fibres, Barrackpore, West Bengal, India with rice-wheat-jute cropping sequence under All India Coordinated Research Project on Long-Term Fertilizer Experiment. They followed four main steps namely, defining goal, selection of minimum data set (MDS) of indicators that best represent soil function, scoring the MDS indicators based on their

performance of soil function, and integration of the indicator score into a comparative index of SQ. The data were reduced to a minimum data set through a series of uni- and multivariate statistical methods using SPSS software. The nonparametric statistics (Kruskal-Wallis x2) were used to identify indicators with significant treatment differences. The standardized principal component analysis (PCA) was performed for each statistically significant variable. Then, selection of MDS variables for each observation was weighted by using the PCA results, the final formula being $SQI = \sum_{i=1}^{n}(Wi \times Qi)$ where, W is the PC weighting factor and S is the indicator score. Here, the assumption is that higher index scores meant better SQ or greater performance of soil functions.

Sharma et al. (2005) studied long term soil management effects on crop yields and SQ in a dryland Alfisol of CRIDA, Hyderabad. They determined SQ index using the following steps, defining goal, selecting a minimum dataset, scoring the MDS indicators based on their performance of soil function and integrating the indicator scores into a comparative index of SQ. The weighted MDS variable scores were then summed up for each observation using the following equation $SQI = \sum_{i=1}^{n} WiSi$ where S is the score for the subscripted variable and Wi is the weighing factor derieved from PCA. Here the assumption is that higher index scores meant better SQ or greater performance of soil function.

Rezaei et al. (2006) assessed SQ in rangelands of Tehran, Iran. The study area is occupied by Lithic and Typic Xerorthents, Typic Haploxerecpts, and Fluvaquents. The Landscape Function Analysis (LFA) method considers rangelands as landscape systems. They selected two MDSs by a procedure that used two different combinations of indicators. The MDS1 included only soil chemical and physical properties; and MDS2 utilized soil properties and landscape function analysis indices. Step 1: They used Pearson correlation coefficients to determine the eligible dependent variables for inclusion in the second step. Step 2: Principal Component Analysis (PCA) was employed as a data reduction tool to select the most appropriate

indicators of site potential for the study area from the list of indicators generated in Step1. Step 3: Multiple regression analysis was considered to be an appropriate tool to assess how well the selected minimum data sets represent range capability (site potential). Thus, this method has been described for selecting the most appropriate soil properties for assessing SQ and the potential of rangelands.

Guilin et al. (2007) established a minimum dataset for SQ assessment based on soil properties and land-use changes at Suzhou city in Shanghai. The selection steps included as i) PCs with eigen value ≥ 1 qualified by PCA analysis. ii) In each qualified PC, those parameters with factor loading ≥ 0.5 were selected as a new group. iii) Sum score was calculated for each parameter. iv) Pearson correlation analysis was conducted to examine the data redundancy between the qualified parameters. The parameter with the highest score was chosen if high correlation (correlation coefficient ≥ 0.5) existed between these qualified parameters and all were chosen if they were lowly correlated. Finally, correlation was undertaken among final MDS sieved from all groups to further reduce the data redundancy.

Dadhwal et al. (2011) developed SQ index for different land use systems in Northwest hilly region of India to assess SQ. The procedure involved identifying appropriate SQ indicators for a minimum dataset (MDS) then transforming those indicators into dimensionless standard scores, and integrating the indicator scores into SQ indices. First, most relevant indicators representing various functions were selected. After selecting the appropriate indicators into unitless score of 0-1, weights were assigned to the indicators depending on their relative importance and sensitivity. The converted values on 0-1 scale were multiplied by weights assigned to them. The aggregate of all the weighted parameters of soil functions defined the state of soil (Q) under each mapping unit as indicated $Q = q_{we}w_{we} + q_{wt}\ w_{wt} + q_{rpd}\ w_{rpd} + q_{rbd}\ w_{rbd} + q_{spg}\ w_{spg}$, where, Q is the soil state or soil condition, q_{wt} is the rating of hydraulic conductivity, q_{wt} is the rating for bulk density, q_{rpd} is the rating for erodibility factor, q_{rbd} is the rating for organic carbon and q_{spg} is the

rating for fertility status of soils and w is the weight factor for each function.

Ping et al. (2013) developed SQ indicator system for hilly red soil region of subtropical China. They first established a minimum dataset for evaluation of SQ by employing a procedure using all soil chemical and physical properties as indicators. It was ensured that those indicators cover a wide range of characteristics and each should affect SQ directly. They used Pearson Correlation coefficient to determine the eligibility of dependant variables for inclusion in the second step of SQ evaluation. Principal component (PC) with eigenvalue > 1 was considered for identifying the MDS1. When more than one variable was retained within a PC, the correlations among those indicators were examined to determine whether any of those variables could be considered redundant for the MDS2. After the final indicators for MDS2 were determined, the weight for each indicator was assigned by its communality, calculated by mathematical statistics of standardized factor analysis. After all indicators in the MDS2 were scored and weighted, SQ index (SQI) was calculated using the method described by $SQI = \sum_{i=1}^{n} (Wi \times Qi)$, where SQI is the soil quality index, Wi is the assigned weight of each indicator, Qi is the indicator score, and n is the number of indicators in the final MDS.

2.2.5 Remote sensing techniques

Since the present study does not include the use of remote sensing technique in assessing soil quality, a detailed review has not been given.

Remote sensing techniques also help in assessing and monitoring soil quality. These techniques allow taking images of the earth surface in various wavelength regions of the electromagnetic spectrum (EMS). One of the major characteristics of a remotely sensed image is the wavelength region it represents in the EMS.

Kristof et al. (1980) conducted a detailed study on identification of soil colour using a double- beam spectrophotometer in the laboratory

by scanning soil samples and in the field by scanning large areas of soils with an airborne multispectral scanner. And they also found that the soils with more than 1.5 % organic matter dramatically decreased soil reflectance throughout the reflective portion of the spectrum.

Guruswamy et al. (1980) used Landsat data of Bhavani dam (southern India) waterspread area and its irrigated lands for mapping soil erosion and suggested that erosion process causes light colour of the surface soil.

Stoner and Biehl (1980) conducted a detailed study using spectroradiometer to measure the spectral signatures of the different soils under laboratory and field conditions. Using degree of saturation instead of volumetric water content as a measure of soil wetness reduced differences between soil types. This facilitated a general model of moisture effects that established soil specific relationship based on mass water content. This was also used to measure spectral response of organic matter content in soil in the spectral range of 0.52 to 0.62 um. The reflectance usually decreases with increasing organic matter content due to dark colour.

Shepherd and Walsh (2000) indicated that erosion prone surfaces in the watershed have geophysical characteristics that are highly distinct in terms of their respective soil reflectance values. They, demonstrated the use of satellite based remote sensing in monitoring soil quality. In controlled soil management experiments, thus correlated the reflectance convolve to Landsat 5 wavelength band passes with various soil quality attributes (R^2 range, 0.26-0.82). It simulated reflectance spectra provided significant ($p<0.001$) relationships, albeit with generally poor fits (R^2 <0.5), moderately good fit (R^2 =0.6) for effective cation exchange property of clay fraction was found, which is a good indicator of clay mineralogy and hence useful for inferring many associated soil properties.

Ray et al. (2004) made efforts to establish relationship between soil quality indicator and remote sensing indices and empirical

equations were developed using combinations of different bands and indices for calculation of soil quality indicators. The decomposition of organic matter can be determined by reflectance curve. Fully decomposed organic fibre reflects in the manner of organic dominated form, whereas well preserved fibres exhibit the higher reflectance.

Remote sensing has limitations in monitoring biological soil quality indicators. No study has yet been carried out to establish relationship between soil organism and reflectance in different segments of electromagnetic spectrum. However, the presence of micro and macro organisms and their activities in soil influence the soil colour, soil texture, etc, which show the robust relationship with electromagnectic spectrum, thus indirectly biological indicators can be monitored through remote sensing by developing a relationship between indicators and changes in soil appearance (Nain et al., 2009).

2.3 Cotton Production in India – General Statistics and Constraint Analysis

2.3.1 General Statistics

Cotton is an important fibre crop of global significance, which is, cultivated in tropical and sub tropical regions of more than seventy countries the world over. The major producers of cotton are China, India, USA, Pakistan, Uzbekistan, Argentina, Australia, Greece, Brazil, Mexico, and Turkey. These countries contribute about 85% to the global cotton production. India, during 2012-13, was the second largest producer of cotton in the world after China, accounting for about 18% of the world cotton production. With 11-12 million ha, India has the distinction of having the largest area under cotton cultivation in the world constituting about 25% of the world area (36.01 million ha) under cotton cultivation. The yield per hectare during 2012-13 in the country is projected to be 489 kg/ha (CCI, 2013).

Cotton is cultivated in three distinct agro-ecological regions (north, central and south) of the country. The northern zone is almost totally irrigated, whereas the percentage of irrigated area is much lower

in the central and southern zones. The central zone has nearly 60% of cotton area of our country. Under the rainfed growing conditions, rainfall ranges from <400 to > 900 mm coupled with aberrant precipitation patterns over the years leading to large scale fluctuations in production. The irrigated tract is drained by canal and well irrigation including the use of micro-irrigation system (Khadi, 2010).

Bt cotton since its release in India in 2002 by Genetic Engineering Approval Committee (GEAC) replaced more and more conventional cotton area. There was an exponential increase in Bt cotton area from 29,000 ha in 2002 to 11.16 m ha in 2010 accounting for a staggering 92% of the total cotton area in India. It is estimated that Bt cotton would cover an area of 15.0 m ha by 2015 (Choudhary and Gaur, 2010). The production increased from 13.6 million ton in 2002-03 to 33.40 million ton during 2012-13 (CCI, 2013) following introduction of Bt cotton.

The major states growing cotton in 2013 in order of hectarage were Maharashtra (4.13 m ha) representing almost half of the total area growing cotton, or 40%, of all cotton area in India in 2012, followed by Gujarat (2.36 m ha or 20%), Andhra Pradesh (2.14 m ha or 16%), Northern Zone (1.56 m ha or 15%), Madhya Pradesh (608,000 ha or 8%), and the rest in Karnataka, Tamil Nadu and other states. The production and productivity of Maharashtra, during 2012-13 was 80.0 lakh bales and 329 kg/ha respectively (CCI, 2013).

Vidarbha is an important cotton growing region in Maharashtra, where a continuous increase in area under cotton crop was recorded, from 15.66 lakh ha (1991-92) to 16.33 lakh ha (1997-98) (Mehetre et al., 2000).

The major districts of interest in Vidarbha in the present investigation are Akola district (AESR 6.3) and Nagpur district (AESR 10.2). The total geographical area of Akola district is 540 ha (in '000) of which during 2012-13, area under cotton cultivation was 168.3 ha (in '000), production was 2689 M ton Lint (in '00) and productivity was 4.18

q/ha (Lint). The total geographical area of Nagpur district is 986 ha (in '000), out of which area during 2012-13 under cotton cultivation was 119 ha (in '000), production was 2300 M ton Lint (in '00) and productivity was 3.28 q/ha (Lint) (Anon, 2013).

2.3.2 Constraint Analysis

General constraints

There are various general constraints observed by different researchers as discussed below.

Impact of weather and economic factors on acreage and production, fluctuations of cotton due to non availability of quality seed, delay in sowing time, suboptimal plant density, inappropriate and inadequate plant protection, multiplicity of genotypes, deficit in the use of important inputs viz. seed and chemical fertilizers, in general, and manure, in particular, compliance of refugia strategy, high price of seed, fertilizers, insecticides and implements, etc. is perceived by most of the farmers. (Kunt and Antani, 1991; Ramasundaram and Gajbhiye, 2001; Ramasundaram, 2003; Navadkar et al., 2005; Dhandhalya and Shiyani, 2006; Ramasundaram et al., 2007; Rai and Singh, 2010; Kumar et al., 2012; CICR Nagpur, 2012; CICR Nagpur, 2013; Bharamagoudar et al., 2013; Singh et al., 2013[a]; Singh et al., 2013[b]; Verma and Devi, 2013).

Soil related constraints

Ramasundaram and Gajbhiye (2001) and Ramasundaram (2003) collected data from 320 cotton farms and identified micro level (field data) constraints such as unsuitable soil.

Monga (2009) studied the soil problems in cultivation of Bt hybrids in north indian cotton zone. They identified major soil constraints as, inadequate crop stand because of poor emergence due to crust formation by rains just after sowing; alkalinity and salinity problems; rising water-table and depletion of water table in some pockets.

2.4 Soil Quality of Cotton Growing Environs with Particular Referance to Vidarbha Region

Yadav et al. (1994) studied impact of crop management and soil-site parameters on growth and yield of cotton. They observed that the optimum crop management, in general, irrespective of the soils significantly increased the seed cotton yield from 6.1 to 10.5 q ha^{-1} in the first year and from 8.4 to 11.2 q ha^{-1} in the second year and so also the maximum root length, leaf area duration and maturity of the crop. Thus, Khapri-5 soil series (Typic Chromustert) is the most preferential soil for cotton followed by Khapri-8 series (Vertic Ustochrept) with appropriate management practices. Khapri-3(a), 4 and 7 (Typic Ustochrepts) soil series were also found to be productive. Hence, it is the crop management in appropriation to the soil resources which help in improving the growth, duration and yield of cotton.

Yadav et al. (1995) studied effect of soil characters on the yield of rainfed crops in a watershed near Nagpur. As per final multivariate analysis carried out between eight important soil characteristics and yield of cotton, the R^2 value was 0.937; thus indicating 93.7 per cent of variability in cotton yield was due to variability in eight soil characteristics.

Yadav et al. (1999) studied soil and site characteristics in relation to yield of cotton in Vidarbha region of Maharashtra. They observed that elevation and coarse fragments did not affect the yield significantly as evidenced by their poor correlations of 0.33 and 0.45 with yield respectively. However, their impact was negative on the yield. Depth ($r = 0.73$), $Y = 2.41 + 0.06X$), clay content ($r = 0.64$, $Y = 14.13 + 0.41 X$) and PAWC ($r = 0.77$, $Y = 2.11 + 0.63 X$) significantly increased the cotton yield whereas influence of slope ($r = 0.68$, $Y = 14.01 - 3.72 X$) was observed to be negative. The EC and CEC did not indicate any limitation but pH above 8.0 had slight limitation for cotton farming. High values of coefficient of determination (R^2), however, indicate that 91% of the variation in the yield of cotton is expressed by these characteristics.

The soils of Purna Valley, Vidarbha, Maharashtra have been studied in great details by researchers in view of a number of constraints they pose to crop production (including cotton).

Nimkar et al. (1992) studied the saline shrink-swell soils of Purna Valley and attributed the cause of salinity to quality of irrigation water. They also reported that due to development of high alkalinity in the soils, the hydraulic conductivity has been adversely affected. Balpande et al. (1996) while reporting sodic soils in the valley have attributed the same to semi-arid climatic conditions. As per studies undertaken by Padole et al. (1998[a]) on soils of the valley, the hydraulic conductivity was low, the organic carbon content was low to moderate, and the ESP was problematic (i. e. > 15).

Padole et al. (1998[b]) studied the water retention and hydualic conductivity of salt affected Vertisols of Purna valley and they observed that the hydrualic conductivity varied from 0.019 to 0.62 cm/hr and was typically low at about 70 cm depth which indicates imperfect to poor drainage of these clayey soils. They concluded that hydraulic conductivity of the soil is adversely affected by soil attributes such as clay, smectite content, bulk density, ESP and SAR. The results further indicate that the clay and smectite content play a dominant role in determining the water retention at both 33 and 1500 kPa tensions whereas no significant influence of organic carbon was observed on water retention at both the tensions.

Mandal et al. (2002) studied suitability mapping for cotton growing soils of Nagpur District. They reported that in Inceptisols which are moderately shallow to very deep (28 cm to 150 cm), clay content varied from 23.9 to 60.8 %, bulk density varied from 1.63 to 1.73 Mg/m^3, pH ranges from 6.5 to 7.9, EC from traces to 0.36 dSm^{-1}, $CaCO_3$ from nil to 46 g kg^{-1}, CEC from 13.4 to 15.6 cmol $(p^+)kg^{-1}$ and base saturation ranged from 85.2 to 97.6 %. On the other hand, Vertisols are moderately deep to very deep (70-160 cm) with clay content varying from 44.2 to 73.7 %, pH from 7.2 to 8.1, EC from 0.17 to 0.30 dSm^{-1}, $CaCO_3$ from nil to 5.5 %, OC from 1.8 to 5.8 g kg^{-1}, CEC

from 32.2 to 63.1 cmol(p^+) kg^{-1} and base saturation varying from 92.9 to 99.7 %.

Kadu et al. (2003) identified properties that influence the yield of deep-rooted crops in 29 Vertisols of semiarid central India. Detailed morphological, physical, chemical, mineralogical and micromorphological studies were carried out since existing land evaluation methods are not adequate to explain the yield of cotton obtained by farmers. The studies indicated that among the soil parameters, $CaCO_3$ in the clay fraction, exchangeable Ca/Mg ratio, exchangeable sodium percentage (ESP) and sHC were the yield influencing factors. The pedogenetic relationship between the semiarid climate, formation of pedogenetic processes that ultimately impair the drainage of soils, evaluation of Vertisols for deep-rooted crops such as cotton on the basis of HC alone may help in planning and management of soils, not only in the Indian semiarid tropics, but also in similar climatic areas elsewhere.

Nayak et al. (2004) established a quantifiable relationship among sand, silt, clay, ECe, CEC and ESP and field capacity (FC), wilting point (WP), available water content (AWC) and sHC (Ks) in a study in saline black soils of Gujarat. They observed that water retention was lower in surface horizon than in subsurface horizons. The clay, silt + clay and CEC had significant positive relationship with FC, WP and AWC, whereas sand and ECe had significant negative correlation. The sHC had significant positive correlation with sand and EC and significant negative correlation with clay, ECe, CEC and ESP. The clay influenced 52.3 per cent variation in saturated hydraulic conductivity. Similarly, ECe caused 89.4 and 72.0 per cent variation on FC and AWC, respectively, whereas CEC had 86.6 per cent variation in WP. Clay, CEC, ECe and ESP jointly accounted for highest variation (89.4%) in saturated hydraulic conductivity and among them clay accounted for 52.3 per cent variation.

Pal et al. (2006) studied naturally degraded Vertisols of Peninsular India and revealed that the formation of pedogenic calcium

carbonate (PC) at the expense of non-pedogenic calcium carbonate (NPC) is the prime chemical reaction for the natural chemical degradation in terms of impairment of hydraulic properties of soils mediated through the development of subsoil sodicity. The characterization of sodic soils in terms of sHC <10mm h^{-1} (weighted mean in 0–100 cm depth of soil) instead of any ESP or sodium adsorption ratio (SAR) emerges as a robust criterion that stands for universal acceptance for the better use and management of such naturally degraded soils, not only in the Indian semi-arid tropics, but also in similar climatic and geologic areas elsewhere.

Sarkar et al. (2008) studied the effects of transgenic Bt cotton in a sub-tropical Inceptisol and observed that Bt cotton may have negative effects on dehydrogenase activity, soil respiration rate and availability of total mineral N in rhizosphrere soils. They also concluded that the time of sampling during plant growth also strongly affected the above parameters, most of which were at their highest values at 60 and 90 DAS.

Yeledhalli et al. (2008) studied productive potential of soils of Tungabhadra project area in Andhra Pradesh for Bt cotton. They observed that the differences in the productivity of Bt cotton were attributed mainly to variations in soil types and soil factors such as clay and organic carbon contents and cation exchange capacity. The ESP values above 10 were found to reduce cotton yields considerably due to dispersion of soil colloids leading to surface encrustation, poor aeration and moisture limitation.

Lingade et al. (2008) studied a Vertisol in Mangali village, Nagpur district, Maharashtra. The study indicated that, the increase in the size and intensity in nodules down the profile, the decrease in the Ca/Mg ratios and increase in Mg and Na ions with depth clearly demonstrate the development of sodicity in soil. The ESP ranged from 7.4 to 34.6 per cent and increased with depth. They concluded that although pedo-climate of Nagpur is characterized by ustic moisture and hyperthermic temperature regimes but as aridity is increasing day by

day, it might result in development of sodicity as these soils carry potential sodicity.

Nawlakhe and Mankar (2010) studied the effect of integrated nutrient management on growth and yield of cotton and green gram intercropping system in clayey soils of Dr. PDKV, Akola, Maharashtra. They observed that use of 25 kg N+ 25 kg P_2O_5 ha^{-1} through inorganic fertilizer + 25 kg N ha^{-1} through FYM treatment recorded maximum height, number of branches and mean total dry matter accumulation. This might be due to supply of nutrients in available form throughout the growth period.

Bhaskar et al. (2011) studied land resource evaluation for optimal land use plans in cotton growing soils of Yavatmal district. They carried out land resource inventory and mapping of shrink-swell soils to evaluate soil site suitability for cotton-based cropping systems, generated soil map with 48 mapping units as soil series associations and interpreted for agricultural land use. They showed that only eighteen percent of land is moderately suitable for cotton against existing fifty two percent of total cultivated area and twenty eight percent areas suitable for sorghum-wheat system.

Velmourougane et al. (2012) studied microbial diversity indices of the agroecological subregions in black soil region of India and they found that microbial diversity indices declined significantly in all the BM spots with increase in soil depth and the maximum diversity was observed in the surface soil. They also found that legume-based and cereal-based cropping system showed higher diversity indices than the cotton based cropping system.

Velmourougane et al. (2013) also studied soil dehydrogenase activity (DHA) in agroecological sub-regions of black soil region of India. They observed that dehydrogenase activity declined with increase in soil depth in all the identified benchmark spots of black soil region. The maximum DHA was recorded in the surface horizon (0-15 cm) and almost 50% of DHA activities were found to be restricted

within 0-30 cm soil depth. The average dehydrogenase activity in different bioclimates was in decreasing order of sub-humid moist>semi-arid dry>sub-humid dry> arid, its activities in different cropping systems were also in decreasing order of legume>cereals>cotton> sugarcane.

CHAPTER - III

MATERIAL AND METHODS

The present investigation was undertaken to assess soil quality in rainfed cotton growing environs of two agroecological sub-regions of Vidarbha namely, AESR 6.3 and AESR 10.2. The materials and methods used for carrying out this investigation are summarised below.

3.1 Materials

3.1.1 Study area details

3.1.2 Field investigations

3.2 Methods

3.2.1 Laboratory investigations

3.2.2 Soil quality (SQ) assessment

3.1 Materials

3.1.1 Study area details

a) Location

The study area constitutes cotton growing soils of different agroecological subregions (AESR) of Vidarbha region of Maharashtra, India, namely, AESR 6.3 and AESR 10.2. AESR 6.3 constitutes Buldhana, Akola, Amaravati, Yavatmal and Jalgaon districts whereas AESR 10.2 constitutes Nagpur and Wardha districts. Location details of selected profiles are given in table 3.1 and fig.3.1 which indicate that six soils in AESR 6.3 have been collected from Akola district and another six soils in AESR 10.2 have been collected from Nagpur district (details of 12 Pedons furnished in Annexure I).

Akola district (AESR 6.3) is situated at Deccan Plateau in between 20° 42' 11" N lattitude and 76° 59' 58" E longitude at an altitude of 285 m above MSL. It lies in the western part of the Nagpur Division of Maharashtra state. It is bounded by Amravati district on the north, Amravati and Washim districts on the east, Washim district on the south and Buldhana district on the west.

Table 3.1 Site location of selected pedons

Pedon No.	Village	Tahsil	Site location	Elevation (above MSL)	Toposheet No.	Soil Depth
AESR 6.3 (Akola district) – hot, moist semi-arid						
Pedon 1	Dongargaon	Akola	20°42 13"N 76°56 55" E	296 m	55 H/2	Very deep (150+ cm)
Pedon 2	Sonori	Akola	20°43 23"N 76°20 25" E	315 m	55 H/6	Shallow (43 cm)
Pedon 3	Mana	Murtizapur	20°46 20"N 76°28 30" E	307 m	55 H/5	Very deep (150+ cm)
Pedon 4	Vallabhnagar	Akola	20°50 17"N 76°59 18" E	273 m	55 H/1	Deep (143 cm)
Pedon 5	Rohana	Akola	20°52 26"N 76°45 21" E	276 m	55 H/1	Deep (120 cm)
Pedon 6	Popatkhed	Akot	21°11 59"N 76°59 57" E	417 m	55D/13	Moderately deep (91cm)
AESR 10.2 (Nagpur District) - hot, dry sub-humid						
Pedon 7	Paradi	Narkhed	21°27 00" N 78°32 16"E	409 m	55 K	Very deep (150+ cm)
Pedon 8	Mangali	Hingana	21°04 04" N 78°55 17" E	312 m	55 P	Deep (140 cm)
Pedon 9	Waroda	Kalmeshwar	21°15 43" N 78°54 36" E	339 m	55 K	Shallow (50 cm)
Pedon 10	Pevatha	Nagpur	21°02 25" N 79°05 14" E	299 m	55 O	Deep (108 cm)
Pedon 11	Sawangi	Hingana	21°52 09" N 78°54 08" E	297m	55 P	Shallow (15 cm)
Pedon 12	Shiva	Nagpur	21°07 22" N 78°44 40" E	393 m	55 K	Very deep (150+ cm)

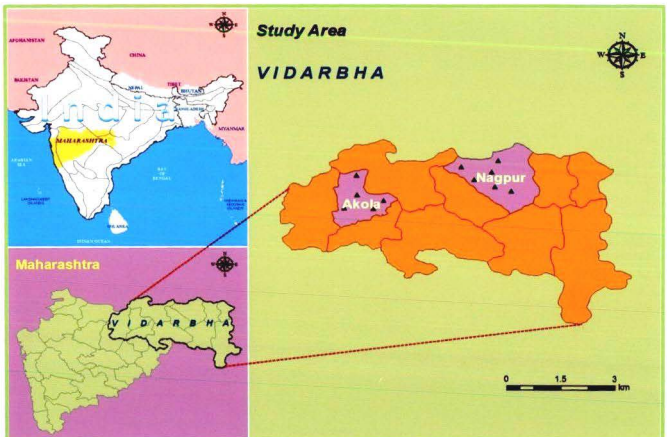


Fig. 3.1 Location Map

Nagpur district (AESR 10.2) is situated at Central Highlands (Malwa, Bundelkhand and Eastern Satpura Range) in between 21° 09' 24" N latitude and 79° 05' 17" E longitude at an altitude of 339 m above MSL. The district is bounded by Chindwada district of MadhyaPradesh state on the north, Bhandara district on the east, Amravati district on the northwest, Chandrapur district on the southeast, Wardha district on the southwest.

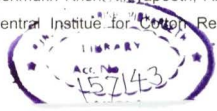
b) Geology

The geology of the region (Akola district) is marked by Deccan trap which covers major part of the district and is characterized by basalt lava flows which are generally dark grey, hard and compact. The entire district, forming part of the Purna valley, is a basin shape depression in the Deccan traps filled by river deposit. The northern edge of the basin in contact with Satpura hills is supposed to be a fault line and covered by boulders and debris derived from the disintegration of the traps.

The geology of the region (Nagpur district) is marked by quartzite, gneiss, schist and marble of Precambrian age, shales and sandstones of the Lower Gondwana, basalt of the upper creataceous and early tertiary period and recent alluvium. To the east of the district is Archean formation consisting of the two lithological units, the gneisses and schists, a younger group of gneisses occurs as a granitic intrusion above metasediments and is found mainly in the northern and south eastern parts of the district. Rocks of lower Gondwana mainly consist of shales, sandstones and the lametas which are found to be fringing along the northwest corner of the district. The entire western part of the district is covered by traps comprising the layers of the doleritic and basaltic lavas.

c) Climate

Monthly weather data were recorded at agro meteorological observatory at Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola for Akola District and at that of Central Institute for Cotton Research,


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Nagpur for Nagpur District, for last 10 years (2002-12) along with corresponding normal values of weather parameters collected for climatic analysis.

Akola district has been classified under hot, moist semi-arid ecosubregion, medium to high AWC and LGP of 120-150 days. In general, more than 90 per cent of rainfall is received during July to September. The average rainfall is 707.3 mm.

The weather from November to February is cool and high temperature is experienced from March to June. The average annual temperature is 27.3°C. May is the hottest month with average maximum temperature being 42.4°C and January is the coldest month with average minimum temperature being 12.3°C. The average relative humidity was recorded as high as 71.3 per cent during the rainy season. Mean climatic parameters and water balance diagram are presented in table 3.2 and fig. 3.2 respectively.

Table 3.2: Mean climatic data of Akola district, Maharashtra

Month	Temperature°C			Rainfall (mm)	Relative humidity (%)		
	Max.	Min.	Mean		8.30 hrs.	17.30 hrs.	Mean
January	29.3	12.3	20.8	11.3	57.8	26.0	41.9
February	32.5	15.1	23.8	1.0	44.7	21.3	33.0
March	37.7	19.8	28.8	7.3	38.3	18.8	28.5
April	41.2	24.9	33.0	6.5	36.0	18.2	27.1
May	42.4	28.5	35.5	13.5	44.3	20.1	32.2
June	37.4	26.7	32.0	114.9	57.7	39.2	48.5
July	31.3	24.2	27.8	229.2	73.0	63.7	68.3
August	30.3	23.5	26.9	139.3	75.3	67.2	71.3
Sept.	31.5	23.1	27.3	117.6	75.4	57.4	66.4
October	33.8	19.3	26.5	34.2	68.0	33.6	50.8
November	31.6	16.4	24.0	29.6	62.9	33.9	48.4
December	29.8	12.9	21.3	2.9	60.6	28.1	44.3
Annual mean total	**34.1**	**20.5**	**27.3**	**707.30**	**57.8**	**35.6**	**46.7**

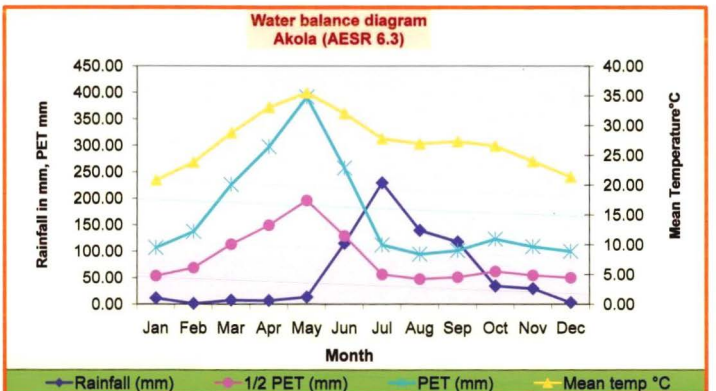


Fig. 3.2 Water balance diagram of Akola district (AESR 6.3)

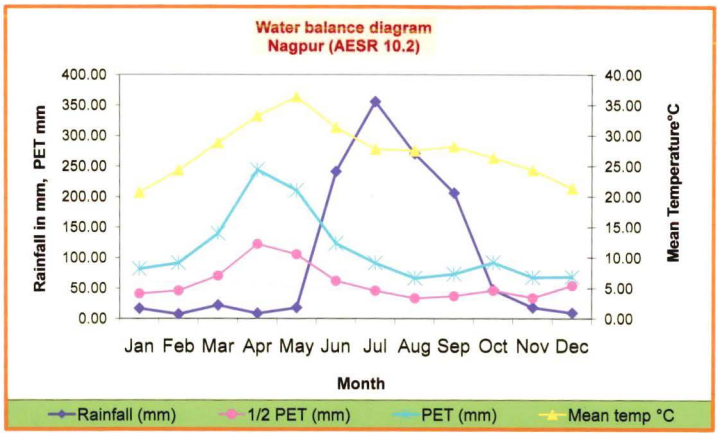


Fig. 3.3 Water balance diagram of Nagpur district (AESR 10.2)

arabia), Mango (*Magnifera indica*), Karanj (*Pongamia pinnata*), Subabul (*Leucaena leucocephala*), Pipal (*Ficus religiosa*), Adulsa (*Justicia adhatoda*), Ashoka (*Saraca indica*). The dominant grass/weed species are doob (*Cynodon dactylon*), kans (*Saccharum spontanieum),* gokhru (*Xanthium strumarium*) and parthenium (*Parthenium hysterophorus*).

e) Present land use

All the selected sites are under agricultural land use, namely, rainfed cotton with pigeon pea as an intercrop in kharif season. During rabi season, wheat and gram are commonly grown. Some of the lands lying in the lower elevation are irrigated and vegetables are grown successfully under irrigation.

3.1.2 Field investigations

a) Site selection – traversing of the study area

Twelve cotton-growing sites, six in each district, were selected for profile studies based on variation in soil depth (shallow, moderetaly deep, deep and very deep), after traversing the area. Profiles were dug at each of the selected twelve sites. The soil-site characteristics such as landform, location, slope, runoff, drainage, erosion, stoniness, land use and natural vegetation were studied and recorded in the profile card as given in Annexure I.

b) Morphological characteristics and sample collection

Morphological examination was carried out as per the procedures laid down in Soil Survey Manual (Soil Survey Staff, 1998). Morphological examination was carried out to study horizonation, depth, colour, texture, structure, consistency, pores and roots, soil reaction and presence of special features such as concretions, pressure faces and slickensides. Detailed morphological descriptions of the 12 pedons are given in Table 4.1.

Horizon-wise soil samples were collected for determining physical and chemical properties whereas for determining biological

properties only surface samples (0-30 cm) from each site were collected.

c) Collection of crop-related information

Information was collected with respect to crop variety (species), dates of planting, doses of fertilizer application, pest control measures and yield data. These information are given in the farmers' questionnaires (Annexure-III). Average yield computation: The yield considered was average of three year, normal, worst and best years.

3.2 Methods

3.2.1 Laboratory Investigations

a) Soil sample processing

The soil samples were air dried at room temperature. The samples were ground using wooden mortar and pestle and sieved through <2 mm sieve. The processed samples of <2 mm size were labeled and stored in polythene bags for subsequent physical and chemical analyses. For soil biological properties, fresh samples were collected during flowering stage of crop and kept in incubator for further analysis.

b) Analysis of soil samples

Soil samples were analyzed for physical, chemical and biological properties by following standard procedures. The methods of analysis followed in laboratory are described below.

i. Physical properties

Particle-size distribution

Particle-size distribution was determined as per international pipette method after removal of cementing agents (organic carbon, $CaCO_3$ and free Fe_2O_3) (Jackson, 1979). The air-dried soil samples (<2 mm) were treated with 1 N sodium acetate (pH 5.0) to destroy calcium carbonate. H_2O_2 (30% v/v) treatment was given to oxidize organic matter followed by citrate-bicarbonate dithionite (CBD) treatment for

the removal of free iron oxides. Sand (2000-50 μm) was separated by wet sieving. Silt (50-2 μm) and clay (2 to <0.2 μm) was separated after dispersion.

Bulk density (BD)

The BD (Mg m^{-3}) of soil was determined by a field moist method using core sampler. The bulk density was calculated by dividing the oven dry weight of soil by corresponding volume of core samplers (Blake and Hartge, 1986).

Saturated hydraulic conductivity (sHC)

The sHC (mm/hr) of a soil is a measure of its ability to transmit water. It is defined by Darcy's law, which for one dimensional vertical flow may be written as

$$Q = -K(\theta)\, \delta H/\delta z$$

Where, Q = is the volume flux density, Darcy velocity or apparent velocity

$\delta H/\delta z$ = the gradient of hydraulic head

$K(\theta)$ = the hydraulic conductivity

The soil samples (<2 mm) were fully saturated and then leached with deionised water. The sHC was determined by constant head method described by Richards (1954) and Klute and Dirckson (1986) calculated on the basis of Darcy's law as mentioned below;

$$K = \frac{Q \times \Delta L}{t \times A \times \Delta H}$$

Where, K = Saturated hydraulic conductivity (cm h^{-1})

Q = Volume of water collected (ml) in time "t"

ΔL = Length of soil column (cm)

ΔH = Hydraulic head (cm).

A = Cross sectional area (cm^2) of soil column.

Water retention

The relation between soil water content and soil water suction is a fundamental part of the characterization of hydraulic properties of a soil. The moisture retention at -33 kPa and -1500 kPa was determined by using pressure plate apparatus (Soil Moisture Equipment Co., Santa Barbara, California). The sieved soil samples in duplicate were filled in rubber soil retainer rings of 6 cm diameter and 1 cm height on ceramic plate of requisite capacity. The soil in the ring was allowed to saturate for 24 hrs with an excess of water and the requisite pressure from a source of compressed air was applied on the next day. Moisture was determined gravimetrically after the soils have attained equilibrium at a particular pressure (Richards, 1954).

ii. Chemical properties

Soil reaction (pH)

The concept of pH is based on the ionic product of pure water. The soil reaction was measured by ELICO pH meter, after equilibrating the soil with water in the ratio of 1:2 soil: water suspension (Jackson, 1973).

Electrical conductivity (EC)

A fairly qualitative estimate of the salt content of the solutions extracted from soils can be made from their electrical conductance. The EC (dSm^{-3}) of soil: water (1:2) suspension was determined by ELICO conductivity bridge (Jackson, 1973).

Organic carbon (OC)

OC content of the soil was determined by Walkley and Black method (Nelson and Sommers, 1982). Ground soil samples of 80-100 mesh were used for estimating organic carbon. Soils were oxidized by 1N potassium dichromate solution in presence of sulphuric acid. The amount of dichromate remaining was determined by back titration with

0.5 N freshly prepared ferrous ammonium sulphate solution using ferroin indicator.

Calcium carbonate ($CaCO_3$)

$CaCO_3$ was determined as per method of Piper (1966). The soils were first treated with hydrochloric acid of known volume and a known strength (0.5 N HCl) to neutralize all carbonates. The soils were heated on a hot plate for about 30 minutes to bring to a condition close to boiling, cooled and filtered. The excess of hydrochloric acid was back titrated with standard NaOH solution using phenolphthalein as an indicator.

Cation exchange capacity (CEC)

For determination of CEC (cmol $p^+ kg^{-1}$), weighed amounts of fine earth samples were saturated with 1 N sodium acetate solution (pH 8.2). After removal of excess sodium acetate by washing with alcohol, the adsorbed Na^+ was extracted by washing with 1 N ammonium acetate (pH 7.0) and the leachate was made up to a known (100 ml) volume. The Na^+ ions present in the leachate were determined by using flame photometer as per methods of Richards (1954).

Exchangeable cations

For determination of exchangeable bases, such as Na^+ and K^+ (cmol $p^+ kg^{-1}$), the samples were saturated with 1 N ammonium acetate solution (pH 7.0). Na^+ and K^+ concentration in the leachate were determined by using flame photometer after standardizing the instrument with different standard solutions prepared with 1N ammonium acetate solution (pH 7.0) of various concentrations of Na^+ and K^+.

For determination of exchangeable bases such as Ca^{2+} and Mg^{2+} (cmol $p^+ kg^{-1}$), the samples were saturated twice successively with1 N NaCl solution. Ca^{2+} and Mg^{2+} concentration in the leachate were determined by using atomic absorption spectrophotometer after

standardizing the instrument with different standard solutions prepared with 1 N sodium chloride solution as per the methods of Piper (1950).

Available nitrogen

It was determined by alkaline potassium permagnate method using Kelplus distillation system by Subbiah and Asija (1956).

Available phosphorus

It was determined by Olsen's method as described by Watanabe and Olsen (1965) using 0.5 M sodium bicarbonate (pH 8.5) as an extractant. Darco-G-60 soluble phosphorus was used to absorb the dispersed organic matter and make the filtrate colourless and complexed by adding ammonium molybdate and thereafter reducing the phospho-molybdate complex in acidic medium. The intensity of the blue colour was measured on colorimeter.

Available potassium

It was determined by the flame photometer using neutral N ammonium acetate (pH 7.0) as an extractant as described by Hanway and Heidel (1952).

DTPA extractable micronutrients (Fe, Mn, Zn and Cu)

The micronutrients were determined by atomic absorption spectrophotometer using DTPA (Diethylene triamine penta acetic acid) extract (pH 7.3) as per method described by Lindsay and Norvell (1978).

iii. Soil biological properties

Soil microbial biomass carbon (SMBC)

Soil microbial biomass was determined using the $CHCl_3$ fumigation-extraction method of Jenkinson and Powlson (1976). Samples of moist soil (10 g) were used and K_2SO_4-extractable C was determined using dichromate digestion. Microbial biomass carbon was calculated using the equation Biomass C= 2.64 EC, where EC =

(organic C in K_2SO_4 from fumigated soil) - (organic C in K_2SO_4 from unfumigated soil).

Dehydrogenase activity (DHA)

DHA was determined following the method of Klein et al. (1971) by the reduction of 2, 3, 5-triphenyl tetrazolium chloride (TTC). Soil (10 g) was incubated for 24 hr with TTC at 27°C in duplicate. The triphenyl formazan (TPF) formed was extracted with acetone and measured spectrophotometrically at 546 nm. Dehydrogenase activity was expressed as µg TPF g^{-1}.

Soil respiration (CO_2 mineralisation)

Soil respiration was measured as the CO_2 evolved from moist soil, adjusted to 55% water holding capacity, and pre-incubated for three days at 22-25 °C with 10 ml of 1M NaOH. The CO_2 production was then measured by back titrating un-reacted alkali with 1 N HCl to determine CO_2-C (Anderson, 1982).

Nitrogen mineralization

Moist soil was saturated with KCl extract and filtered. The filtrate was taken in distillation tube, MgO was added to it for distillation as ammonia is trapped in boric acid mixed indicator. Devarda Alloy was then added in the same distillation tube and kept with another boric acid mixed indicator. Then both boric acid mixed indicators were titrated against 0.02 N H_2SO_4 till the colour changed from light green to pink. Ammonical nitrogen and nitrate nitrogen were determined as per alkaline permanganate method described by Piper (1966).

Particulate organic matter (POM)

The soil samples were dispersed in sodium hexametaphosphate by reciprocal shaking for 15 hrs. Then it was passed through a 53 µm sieve with the help of rising distilled water for several times; the material that was retained on sieve was dried at 50^0C overnight. The dried sample was ground with a mortar and pestle and analysed for

POM as per wet oxidation method described by Cambardella and Elliott (1992).

Culturalable microbial population

Soil samples collected were serially diluted up to 10^{-5} dilution and 1 ml of aliquot was pour plated in selective media (Nutrient Agar for bacteria, Martin's Rose Bengal Agar for fungi, Ken Knights and Munaier's Agar for actinomycetes and Buffered Yeast Agar for yeast). The plates were incubated at optimum temperature (28°C ± 1°C for bacteria and yeast; 30°C ± 1°C for fungi and actinomycetes) in triplicates. The microbial colonies appearing after the stipulated time period of incubation (3 days for bacteria and yeast; 5 days for fungi; 7 days for actinomycetes) were counted as total culturable colony forming units and expressed in $\log_{10}$ cfu g^{-1} of the sample as per method described by Dhingra and Sinclair (1993).

Microbial diversity index

Biodiversity concerns spatial variability of species and individuals within ecosystems and no single quantitative index of biological diversity can measure the magnitude and direction of climatic, cropping systems, land use and management variations. Hence for the present study, we used multiple diversity indices (richness and dominance) to measure the diversity of microorganisms. The microbial diversity indices [Shannon-Weaver index (H´); Simpson's index (D), Shannon evenness index (E1) and Simpson evenness index (E2)] were determined as per the relationships given below. The microbial diversity indices were determined by Hill et al. (2003).

a. **Shannon-Weaver index (H´)** was chosen as index of species of relative abundance or richness using the equation,

$$H' = \sum_{i=1}^{s} pi \ln pi$$

Where, s equals the number of species and *pi* is the proportion of the individual found in the i^{th} species, ln denotes natural logarithm.

b. Simpson's index (D) was chosen as index of dominance using the equation,

$$D = \Sigma \left(\frac{ni(ni-1)}{N(N-1)} \right)$$

Where, *ni* is the number of individuals of the i^{th} species and *N* is the total number of individuals for all s species in the sample.

c. Shannon evenness index (E1) or Species equitability index was calculated using the equation,

$$E = \frac{H'}{\ln S}$$

Where, *E* = Equitability/Evenness index, *H'* = Shannon-Weiner index, S = number of species in a population

d. Simpson's evenness index (E2) was calculated using the equation,

$$E = \frac{D}{\ln S}$$

Where, *E* = Equitability/Evenness index, *D* = Simpson's index, S = number of species in a population

3.2.2 Soil quality (SQ) assessment

Often SQ assessment methods use a number of parameters (SQ indicators) that are neither mutually exclusive nor locally relevant and hence fail to produce results that are of pragmatic value. There arises a need of identifying a minimum set of data i.e. a MDS of SQ indicators that are mutually exclusive and locally relevant to enable assess SQ appropriately, effectively and meaningfully.

The MDS is developed using various approaches one using expert knowledge and the other through use of Pearson's correlation and Principal Component Analysis (PCA).

3.2.2.1 Development of MDS using expert knowledge

Selection of the attributes for developing MDS comprising physical, chemical and biological properties of soils (that best represent soil functions) was carried out using expert knowledge (Chatterji, 2000;

Kadu et al., 2003; Venugopalan et al., 2009 and Kundu et al., 2012). The MDS of attributes so developed through expert knowledge were used for assessing SQ through two approaches namely, one based on computation of Relative Soil Quality Index (RSQI) and the other based on computation of Composite Soil Index (CSI) using fuzzy modelling.

A. SQ assessment based on RSQI – A conventional method

The following five steps were followed to assess soil quality through development of a soil quality index based on RSQI computations.

a. Assessment of weightages to each attribute depending on available knowledge about its relative role in influencing crop yield and also on the basis of soil conditions, cropping pattern and agro-climatic conditions of study area as also done by Davidson et al. (1994). Weightages are given on 0 to 100 scale and sum of all the weights was normalized to 100 %.

b. Scoring of attributes: The status of the each attribute was categorized according to class along with its score. The range of score varied from 1 to 4, so the theoretical range of SQI was 100 to 400 i.e. the minimum value of SQI was 100 and maximum value of SQI 400 (Wang and Gong, 1998).

c. Computation of SQI as per the method described by Karlen and Stott (1994) and Kundu et al. (2012).

$$SQI = \pounds\ Wi\ Mi,$$

where, Wi = weight of i^{th} indicator and Mi = marks of i^{th} indicator class

Besides, relative soil quality index (RSQI) was determined using the following relationship for judging the SQI value of any site against maximum theoretical value

$$RSQI = \frac{SQI\ of\ the\ given\ site}{Maximum\ theorotical\ value\ of\ SQI} \times 100$$

d. Categorisation of the RSQI: RSQI values of less than 50% were categorized as belonging to poor, 50-70% as medium and more than 70% % was categorized as good quality soil.

e. Correlation of the values of RSQI with average yield for validation.

B. SQ assessment using mathematical approach (fuzzy modelling-based method) –Soil Quality was assessed using relatively modern method of fuzzy mathematical tool.

This method consists of three steps like generation of membership values for the soil characteristics, determination of weights for the membership values, and combination of weighted membership values to produce a composite soil index (CSI) (Burrough, 1989 and Chatterji, 2000).

a.

$$\sum_{A}\mu(z) = \frac{1}{1 + a_i (z_i - c_i)^2} \text{for } 0 \le z \le £ \quad \ldots\ldots (1)$$

Where A is the soil characteristic set; a is the dispersion index that determines the shape of the function, c (called the ideal point or standard index) is the value of the property z at the center of the set and £ is the maximum value that z can take.

b. The Joint Membership function (JMF) for each pedon and for each parameter was computed using the convex combination rule, which is a linear weighted combination of membership values of each land characteristic A_i

$$I = \sum_{i=1}^{N} w_i \mu \quad \ldots\ldots(2)$$

Where I is the joint membership function and w_i are the weights of the memberships value μ

c. To ensure that weights sum up to unity, the rank r_i of a land characteristic, A was converted to weight W_i using the equation:

$$Wi = \frac{r_i}{\sum_{i=1}^{n} r} \quad \text{..... (3)}$$

Equation (2) shows that the choice of weights W_i is crucial in the determination of the overall land suitability index.

d. Simple ranking procedure was used in deriving weights. This ranking was based on literature (Sys 1985; NBSS & LUP, 1994; Kadu et al., 2003; Naidu et al., 2006) which indentified the relative importance of a particular parameter to the cultivation of cotton crop.

e. The composite soil index (CSI) of a SQ parameter was determined as the average of the aggregated JMF values of the parameters for a particular pedon which in concept and for all practical purposes holds the same implication as that by SQI.

f. The suitability classes for the crops were identified by placing the CSI values in a set of equally-spaced classes on a 0-100 scale, with a 20 unit gradation. CSI lying between 100-80 comes under class I, CSI lying between 80-60 comes under class II, CSI lying between 60-40 comes under class III, CSI between 40-20 comes under class IV and class V has CSI values ranging from 20-0.

g. The composite soil index (CSI) values were correlated with average yield for validation.

3.2.2.2 Development of MDS using Principal Component Analysis (PCA)

Selection of indicators and Identification of Minimum Dataset (MDS): Pearson's correlation matrix among average yield of cotton crop and soil properties were developed for initial screening of indicators. Those parameters which are mutually exclusive and locally relevant having significant correlation (two tailed test, $p<0.05$) with average yield were considered for PCA.

PCA was done using SPSS software version 11.5. The principal components receiving high eigen values (>0.9) were able to explain >80 % variations having high factor loading were assumed as the variables that best represent system attributes (Brejda et al., 2000).

PCA-based SQ assessment

The following steps were followed to develop SQI and thus assess SQ.

a. Weightages of the MDS indicators: The MDS variables for each observation were weighted by using the PCA results. Each PC explained a certain amount (%) of the variation in the total data set. This percentage, divided by the total percentage of variation explained by all PCs with eigenvectors greater than 0.9, provided the weighted factor for variables chosen under a given PC.

b. Scoring of MDS indicators: Each of the MDS variables was scored on the basis of performance of soil function, considering soil type and variation of values within pedons. Each variable was transformed or standardized to a value between 0.1 (least favorable soil function) and 1 (most favorable soil function) scoring function (Andrews et al., 2002[b]).

c. Soil Quality Index (SQI): The soil quality index was worked out by using following equation suggested by Sharma et al. (2005) and Chaudhury et al. (2005),

$$SQI = \sum Wi\, Si$$

where, Wi = weight of i^{th} indicator using PCA

and Si= score of i^{th} indicator

Here, the assumption is that higher index scores mean better soil quality or greater performance of the soil functions.

d. Correlation of the Soil quality index (SQI) with average yield (Draper and Smith, 1981).

CHAPTER - IV

RESULTS AND DISCUSSION

The study was undertaken to characterise dominant cotton growing soils of the two agroecological subregions (AESRs) of Vidarbha viz., AESR 6.3 (Akola district) and AESR 10.2 (Nagpur district) in terms of physical, chemical and biological properties and assess their quality for cotton cultivation. It may be worth mentioning here that, till recent times, biological properties had been seldom used in developing soil quality index. The need for their use was felt subsequent to the realisation that soil quality is an integrated concept encompassing broad range of physical, chemical and biological properties that could be used to assess its quality. Soil needs to be viewed as an integrated system. Hereafter, whenever soil quality index (SQI) is discussed (in the thesis) it will mean Integrated SQI (except when discussed with respect to SQ assessment by fuzzy modelling).

The results obtained are presented and discussed in this chapter under the following subheads.

4.1 Morphological properties of soils

4.2 Physical properties of soils

4.3 Chemical properties of soils

4.4 Nutrient status of soils

4.5 Biological properties of soils

4.6 Seed cotton yield

4.7 Soil quality assessment using different methods

4.1 Morphological properties of soils

The morphological properties of the pedons under investigation are presented in Table 4.1.

4.1.1 Soil colour

Soil colour plays an important role in all major soil classifications and for all means of soil interpretations. In the field, it is determined through visual comparison of a small, fresh soil sample with colour chips in standard colour charts. The most familiar and widely used colour chart is the Munsell soil colour chart. The Munsell colour scheme is an objective three coordinate system that defines colour through its hue (shade), value (lightness) and chroma (intensity/ saturation) which are combined in that order to form the colour designation.

In AESR 6.3, pedons 1, 3 and 4 exhibited very dark grayish brown (10 YR 3/2) to dark grayish brown (10 YR 4/2) colour. Pedon 2 exhibited dark brown (10 YR 3/3) to dark grayish brown (10 YR 4/2) colour; pedon 5 exhibited very dark grayish brown (10 YR 3/2) to brown (10 YR 4/3) colour and that of pedon 6 exhibited very dark grayish brown (10 YR 3/2) colour.

In AESR 10.2, pedons 8, 11 and 12 exhibited very dark grayish brown (10 YR 3/2) colour; pedon 7 exhibited very dark grayish brown (10 YR 3/2) to dark grayish brown (10 YR 4/2) colour; pedon 9 exhibited dark brown (10 YR 3/3) colour and pedon 10 exhibited very dark grayish brown (10 YR 3/2) to dark brown (10 YR 3/3) colour.

4.1.2 Structure

The term 'soil structure' refers to arrangement of primary and secondary particles into a certain structural pattern. Soil structure is an important characteristic of the soil. The various soil management practices such as tillage, cultivation, application of fertilizers and manures, amendments and irrigation bring about change in soil structure which influences other soil properties (microbial and biochemical) that affect root growth, water and nutrient uptake, crop growth and yield.

Table 4.1 Morphological properties of soils

Horizon	Depth (cm)	Boundary		Matrix colour	Texture	Structure	consistence			Pores		Nodules		Roots		Effervescence	Pressure faces/slickensides
		D	T			S G TY	D	M	W	S	Q	S	Q	S	Q		
AESR 6.3																	
Pedon 1 (Dongargaon): Fine, smectitic (calcareous), hyperthermic Typic Haplusterts																	
Ap	0-17	c	s	10 YR 3/2	c	m2sbk	h	fr	sp	f	m	f	m	m	m	es	-
Bw1	17-49	g	s	10 YR 3/2	c	m2sbk	h	fr	sp	f	m	f	c	fm	m	es	-
Bw2	49-84	g	s	10 YR 4/2	c	m3abk	-	fi	sp	-	-	m	c	vf	fc	ev	pf
Bss1	84-107	g	s	10 YR 4/2	c	m3abk	-	fi	vsvp	-	-	m	c	vf	fc	ev	ss
Bss2	107-150+	-	-	10 YR 4/2	c	m3abk	-	fi	vsvp	-	-	m	c	vf	f	ev	ss
Pedon 2 (Sonori): Loamy, smectitic, hyperthermic Lithic Haplustepts																	
Ap	0-19	c	s	10 YR 3/3	cl	m2sbk	sh	fr	sp	f	m	f	f	m	f	-	-
Bw	19-43	c	s	10 YR 4/2	sicl	m3abk	-	fr	sp	-	-	-	-	vf	f	-	-
Cr	43+	----------Weathered Basalt----------															
Pedon 3 (Mana): Fine, smectitic (calcareous), hyperthermic Typic Haplusterts																	
Ap	0-15	c	s	10 YR 3/2	c	m2sbk	h	fr	sp	f	m	f	m	fc	m	es	-
Bw	15-45	g	s	10 YR 4/2	c	m2sbk	h	fr	sp	-	-	fm	m	f	m	es	pf
Bss1	45-83	g	s	10 YR 4/2	c	m2abk	-	fi	vsvp	-	-	fm	c	vf	fc	es	ss
Bss2	83-150+	-	-	10 YR 4/3	c	m3abk	-	fi	vsvp	-	-	m	c	vf	fc	ev	ss
Pedon 4 (Vallabhanagar): Very-fine, smectitic (sodic), hyperthermic Typic Haplusterts																	
Ap	0-19	c	s	10 YR 3/2	c	m2sbk	h	fr	sp	vf	fm	c	m	m	m	ev	-
Bw1	19-46	c	s	10 YR 3/2	c	m2sbk	h	fr	sp	vf	fm	c	m	m	m	ev	pf
Bw2	46-71	g	s	10 YR 3/2	c	m2sbk	h	fr	vsvp	-	-	m	m	fm	mf	ev	ss
Bss1	71-98	g	s	10 YR 3/2	c	m2sbk	-	fi	vsvp	-	-	fm	fc	vf	fc	es	ss
Bss2	98-120	g	s	10 YR 3/2	c	m2sbk	-	fi	vsvp	-	-	vf,fc	mf	vf	f	es	ss
Bss3	120-143	-	-	10 YR 4/2	c	m2sbk	-	fi	vsvp	-	-	vf,fc	f	vf	f	es	ss

Contd....

Horizon	Depth (cm)	Boundary		Matrix colour	Textu re	Structure	consistence			Pores		Nodules		Roots		Efferv escen ce	Pressure faces/slick ensides
		D	T			S G TY	D	M	W	S	Q	S	Q	S	Q		
Pedon 5 (Rohana): Very-fine, smectitic (calcareous), hyperthermic Typic Haplusterts																	
Ap	0-17	c	s	10 YR 3/2	c	m2sbk	h	fr	sp	f	m	c	m	m	m	es	-
Bw	17-43	g	s	10 YR 3/2	c	m2sbk	h	fr	sp	vf	fm	c	m	fm	m	es	pf
Bss1	43-69	g	s	10 YR 3/2	c	m2sbk	-	fi	sp	vf	fm	vf	f	vf	fc	e	ss
Bss2	69-98	g	s	10 YR 4/3	c	m3abk	-	fi	sp	-	-	vf	f	vf	fc	e	ss
Bss3	98-120	-	-	10 YR 4/3	c	m3abk	-	fi	sp	-	-	vf	f	vf	f	e	ss
Pedon 6 (Popatkhed): Very-fine, smectitic (calcareous), hyperthermic Vertic Haplustepts																	
Ap	0-17	c	s	10 YR 3/2	c	m2sbk	sh	fr	sp	vf	fm	vf	fm	fm	m	e	-
Bw1	17-35	g	s	10 YR 3/2	c	m2sbk	-	fi	vsvp	-	-	vf	fc	fm	m	e	-
Bw2	35-70	g	s	10 YR 3/2	c	m2sbk	-	fi	vsvp	-	-	vf	f	vf	fc	e	pf
Bw3	70-91	-	-	10 YR 3/2	c	m2sbk	-	fi	vsvp	-	-	vf	f	vf	f	e	pf
AESR 10.2																	
Pedon 7 (Paradi): Fine, smectitic (calcareous), hyperthermic Typic Haplusterts																	
Ap	0-15	c	s	10 YR 3/2	c	m2sbk	h	fr	sp	f	m	vf	fm	m	m	e	-
Bw1	15-31	g	s	10 YR 4/2	c	m2sbk	h	fr	sp	vf	fm	vf	fc	m	m	e	-
Bw2	31-52	g	s	10 YR 3/3	c	m2sbk	h	fr	sp	vf	fm	vf	fc	fm	c	e	pf
Bss1	52-83	g	s	10 YR 4/2	c	m2sbk	-	fi	vsvp	-	-	vf	fc	fm	fc	e	ss
Bss2	83-115	g	s	10 YR 4/2	c	m3abk	-	fi	vsvp	-	-	fm	mf	vf	fc	es	ss
Bss3	115-130	g	s	10 YR 4/2	c	m3abk	-	fi	vsvp	-	-	fm	mf	vf	f	es	ss
Bss4	130-150+	-	-	10 YR 4/2	c	m3abk	-	fi	vsvp	-	-	fm	mf	vf	f	es	ss

Contd....

Horizon	Depth (cm)	Boundary		Matrix colour	Textu re	Structure	consistence			Pores		Nodules		Roots		Efferv escen ce	Pressure faces/slick ensides
		D	T			S G TY	D	M	W	S	Q	S	Q	S	Q		
Pedon 8 (Mangli):Very-fine, smectitic (calcareous), hyperthermic Typic Haplusterts																	
Ap	0-10	c	s	10 YR 3/2	c	m2sbk	vh	vfr	ss	vf	fm	vf	fc	m	m	e	-
Bw	10-32	c	s	10 YR 3/2	c	m2sbk	vh	fr	sp	vf	fm	vf	fc	m	m	e	pf
Bss1	32-54	g	s	10 YR 3/2	c	m3abk	vh	fr	sp	-	-	vf	fc	fm	c	e	ss
Bss2	54-81	g	s	10 YR 3/2	c	m3abk	vh	fr	sp	-	-	fm	mf	fm	fc	es	ss
Bss3	81-110	g	s	10 YR 3/2	c	m3abk	-	fi	vsvp	-	-	fm	mf	vf	fc	es	ss
Bss4	110-140	g	s	10 YR 3/2	c	m3abk	-	fi	vsvp	-	-	fm	mf	vf	f	es	ss
Bc	140	---------- Weathered basalt ----------															
Pedon 9 (Waroda): Loamy, smectitic, hyperthermic Lithic Haplustepts																	
Ap	0-10	c	s	10 YR 3/3	cl	m2sbk	sh	fr	sp	vf	f	-	-	f	f	-	-
Bw	10-35	c	s	10 YR 3/3	cl	m2sbk	-	fr	sp	-	-	vf	F	-	-	nil to e	-
Cr	35-50	----------Weathered basalt----------															
R	50+	----------Hard rock----------															
Pedon 10 (Pevatha): Very-fine, smectitic, hyperthermic Vertic Haplustepts																	
Ap	0-15	c	s	10 YR 3/2	c	m2sbk	h	fr	sp	f	m	vf	f	m	m	-	-
Bw1	15-35	c	s	10 YR 3/2	c	m2sbk	-	fr	sp	f	m	vf	f	fm	c	nil to e	-
Bw2	35-58	c	s	10 YR 3/2	c	m2sbk	-	fi	sp	-	-	vf	f	fm	fc	nil to e	-
Bw3	58-85	c	s	10 YR 3/3	c	m3abk	-	fi	sp	-	-	vf	mf	vf	fc	e	-
Bw4	85-108	-	-	10 YR 3/3	c	m3abk	-	fi	sp	-	-	vf	mf	vf	f	es	-
Pedon 11 (Asola): Clayey, smectitic (calcareous), hyperthermic Lithic Ustorthents																	
Ap	0-15	c	s	10 YR 3/2	c	m2sbk	h	fr	sp	f	F	vf	mf	vf	fc	es	-
Cr	15-40+	----------Weathered Basalt----------															

Contd....

Horizon	Depth (cm)	Boundary		Matrix colour	Textu re	Structure	consistence			Pores		Nodules		Roots		Efferv escen ce	Pressure faces/slick ensides
		D	T			S G TY	D	M	W	S	Q	S	Q	S	Q		
Pedon 12 (Shiva): Fine, smectitic (calcareous), hyperthermic Vertic Haplustepts																	
Ap	0-10	c	s	10 YR 3/2	c	m2sbk	h	fr	sp	vf	fm	vf	fc	m	m	e	-
Bw1	10-38	d	s	10 YR 3/2	c	m2sbk	h	fr	sp	vf	fm	vf	fc	m	c	e	pf
Bw2	38-59	d	s	10 YR 3/2	c	m2sbk	-	fi	sp	-	-	vf	fc	fm	fc	e	pf
Bw3	59-82	d	s	10 YR 3/2	c	m2sbk	-	fi	sp	-	-	vf	fc	vf	fc	e	pf
Bw4	82-100	d	s	10 YR 3/2	c	m3abk	-	vfi	vsvp	-	-	vf	fc	vf	f	e	pf
Bw5	100-150+	-	-	10 YR 3/2	c	m3abk	-	vfi	vsvp	-	-	-	-	-	-	es	-

- Abbreviations are according to Soil Survey Manual (Soil Survey Staff,1951)

  Boundary: D = Distinctness; a – abrupt, c – clear; g – gradual, d - diffuse; T= topography; s – smooth; w – wavy, i – irregular, b - broken

  Texture: s- sand, lfs- loamy fine sand, ls- loamy sand, sl- sandy loam, l- loam,sil- silt loam, si- silt, scl- sandy clay loam, cl- clay loam, sicl- silty clay loam, sc- sandy clay, c- clay; sic-silty clay

  Coarse fragments: fg-fine grained (<2.5 cm); cg-coarse gravel(2.5-7.5 cm); st- stony(7.5-25.0), b-boulders (>25.0cm)

  Structure: S = size; vf- very fine, f- fine, m = medium, c- coarse, vc- very coarse; G = grade;1- weak, 2- moderate; 3- strong; T=Type, gr- granular, cr- crumb, cpr-columnar, pr- prismatic, pl- platy, sbk- subangular blocky, abk- angular blocky, sg- single grain, m- massive

  Consistence: D = dry, l- loose,s- soft,sh = slightly hard, h = hard, vh- very hard,eh- extremely hard; M = moist; l- loose, vfr = very friable, fr = friable,fl- firm, vfl- very firm, efl- extrealy firm; W = wet; so- non sticky, ss- slightlysticky,s-sticky, vs- very sticky,po- non plastic, ps- slightly plastic, p-plastic, vp- very plastic..

  Porosity/ Cutans/ Nodules: S-size, vf- very fine, f-fine, m- medium, c- coarse; Q=Quantity, f-few, c-common, m-many.

  e- slightly effervescent, es- strongly effervescent, ev- violent effervescence; pf- pressure faces

In AESR 6.3 (Table 4.1), the Ap and Bw1 horizons of Pedon1 had moderate medium subangular blocky structure. The horizons (Bw2, Bss1 and Bss2) were associated with pressure faces and slickensides which break into strong medium angular blocky structure. Pedon 2 had moderate medium subangular blocky structure in surface horizon (Ap) and the subsurface horizon (Bw) was associated with strong medium angular blocky structure. The Ap and Bw horizons of Pedon 3 had moderate medium subangular blocky structure, Bss1 had moderate medium angular blocky structure and Bss2 had strong medium angular blocky structure with slickensides. All the horizons of Pedon 4 had moderate medium subangular blocky structure and was associated with pressure faces and slickensides Pedon 5 had moderate subangular blocky structure in Ap, Bw and Bss1 and strong medium angular blocky structure in Bss2 and Bss3 associated with pressure faces and slickensides. Pedon 6 had moderate medium subangular blocky structure associated with pressure faces.

In AESR 10.2 (Table 4.1), Pedon 7 had moderate medium subangular blocky structure in Ap, Bw1, Bw2 and Bss1 horizons and strong medium angular blocky structure in Bss3 and Bss4 horizons, associated with pressure faces and slickensides. Pedon 8 had moderate medium subangular blocky structure in surface (Ap) and subsurface horizons (Bw) whereas remaining horizons (Bss1, Bss2, Bss3 and Bss4) had strong medium angular blocky structure. Pedon 9 had moderate medium subangular blocky structure in surface (Ap) and subsurface (Bw) horizons. Pedon 10 had moderate medium subangular blocky structure in Ap, Bw1 and Bw2 horizons and strong medium angular blocky structure in Bw3 and Bw4 horizons. Pedon 11 had moderate medium subangular blocky structure. Pedon 12 had moderate medium subangular blocky structure in Ap, Bw1, Bw2 and Bw3 horizons and strong medium angular blocky structure in subsurface horizons (Bw4 and Bw5) and was associated with pressure faces and slickensides.

4.1.3 Depth

Depth is a measure of the distance from the surface of the soil to a root restrictive layer that has stone, water table, or hardpan (dense soil layer).

The pedons under study showed (Table 4.1) variation in soil depth and were grouped under various categories viz., shallow (< 50 cm), moderately shallow (50-75 cm), moderately deep (75-100 cm), deep (100- 150 cm) and very deep (>150) as per Soil Survey Manual (Soil Survey Staff, 1998).

In cotton growing soils of AESR 6.3, pedon 2 (43 cm) was shallow; pedon 6 (91 cm) was moderately deep; pedons 4 (143 cm) and 5 (120 cm) were deep; pedons 1 (150+ cm) and 3 (150+ cm) were very deep. In AESR 10.2, out of six cotton growing soils, pedon 11 (15 cm) and Pedon 9 (35 cm) were shallow; Pedons 10 (108 cm) and 8 (140 cm) were deep; pedons 7(150+ cm) and 12 (150+ cm) were very deep.

4.2 Physical properties of soils

4.2.1 Particle size distribution

The distribution of particle size is partitioned into sub-fractions of sand, silt and clay, the proportions of which have a dominant influence on many of the practical soil properties important for agriculture, environment and engineering purposes, such as ease of cultivation, nutrient and water holding capacities, transmission characteristics, earth dam construction and susceptibility to erosion. Several systems of classification of soils on the basis of particle-size classes are used to interpret soils for their agricultural or non-agricultural uses. However, the variation in contents of sand, silt and clay depend on geological formations.

Data (Table 4.2) showed that in AESR 6.3 the pedons had high clay content except pedon 2. The clay contents ranged from 53.6 to 68.1 percent and gradually increased with depth. Pedon 2 had low clay content in surface horizon (39.8 percent) and in subsurface (25.2

percent) horizon. The silt contents in the pedons ranged from 24.8 to 40.9 per cent and its distribution with depth was almost uniform. The sand content was less than 1 per cent in pedon 3 (0.79 to 0.97 per cent) and pedon 4 (0.44 to 0.53 per cent), whereas in case of pedon 5, sand content was 0.76 to 7.95 percent. In pedon 1, sand content ranged from 1.58 to 6.8 percent and in pedon 6, sand content ranged from 4.9 to 7.55 percent showing no specific trend.

In AESR 10.2, the pedons (except pedon 9) had high clay content that ranged from 56.4 to 67.8 percent, however, clay distribution down the profile showed irregular trend. Pedon 9 had comparatively lower clay content in surface horizon (33.19 percent) and in subsurface horizon (36.11 percent). The silt content in the pedons ranged from 22.13 to 40.43 percent showing no specific trend with depth. The sand contents were low in pedons 7, 8, 10, 11 and 12 that ranged from 0.45 to 16.88 percent whereas pedon 9 had high sand content relative to other pedons viz., 30.73 percent in surface horizon and 34.47 percent in subsurface horizon. Since all the pedons are derived from basaltic parent material, they had high clay content. It is advocated that as the immediate weathering product of basalt is smectite, hence more clay was observed in soils developed on basalt (Bhattacharyya et al., 1993). Less proportion of sand in these pedons indicate that these soils are developed from the alluvium of the Deccan basalt (Pal and Deshpande, 1987).

4.2.2 Bulk density (BD)

BD is a key soil physical property that is indicative of the degree of compactness. It is used as an indicator of soil aeration status (together with soil and water content). It depends on compaction as well as the structural conditions. It, therefore, tends to vary with soil texture, which determines the packing of soil particles.

Table 4.2 Physical properties of soils

Horizon	Depth (cm)	Particle Size (%)			Textural Class	BD	Water Retention (%)		AWC (%)	sHC (mm/hr)
		Sand	Silt	Clay		(Mg/m^3)	at 1/3 bar	at 15 bar		
AESR 6.3										
Pedon 1 (Dongargaon): Fine, smectitic (calcareous), hyperthermic Typic Haplusterts										
Ap	0-17	1.58	39.08	59.34	clay	1.72	34.48	22.43	12.05	1.34
Bw1	17-49	1.86	38.95	59.19	clay	1.68	34.89	23.76	11.13	1.17
Bw2	49-84	4.52	36.49	58.99	clay	1.70	31.58	21.04	10.54	0.85
Bss1	84-107	4.63	36.17	59.20	clay	1.69	34.75	22.96	11.79	0.19
Bss2	107-150+	6.80	39.54	53.66	clay	1.71	28.55	17.36	11.19	0.20
Pedon 2 (Sonori): Loamy, smectitic, hyperthermic Lithic Haplustepts										
Ap	0-19	22.46	37.71	39.81	clay loam	1.61	27.60	14.45	13.16	1.69
Bw	19-43	33.89	41.08	25.02	silt clay loam	-	22.01	10.83	11.18	3.13
Pedon 3 (Mana): Fine, smectitic (calcareous), hyperthermic Typic Haplusterts										
Ap	0-15	0.97	38.19	60.84	clay	1.67	35.79	20.70	15.09	3.23
Bw	15-45	0.87	40.71	58.42	clay	1.69	31.49	17.91	13.58	3.13
Bss1	45-83	0.93	39.83	59.24	clay	1.71	34.99	20.14	14.85	1.64
Bss2	83-150+	0.79	40.95	58.26	clay	1.63	31.55	17.36	14.19	1.59

Contd....

Horizon	Depth (cm)	Particle Size (%)			Textural Class	BD (Mg/m^3)	Water Retention (%)		AWC (%)	sHC (mm/hr)
		Sand	Silt	Clay			at 1/3 bar	at 15 bar		
Pedon 4 (Vallabhanagar): Very-fine, smectitic (sodic), hyperthermic Typic Haplusterts										
Ap	0-19	0.52	32.02	67.45	clay	1.57	43.25	27.93	15.32	1.82
Bw1	19-46	0.44	34.40	65.16	clay	1.64	41.41	26.82	14.59	1.45
Bw2	46-71	0.45	35.40	64.16	clay	1.58	40.64	25.91	14.73	0.51
Bss1	71-98	0.48	31.50	68.01	clay	1.62	43.83	27.86	15.97	0.30
Bss2	98-120	0.45	31.44	68.12	clay	1.63	44.07	28.93	15.14	0.10
Bss3	120-143	0.53	34.08	65.40	clay	1.48	41.85	26.50	15.35	0.20
Pedon 5 (Rohana): Very-fine, smectitic (calcareous,) hyperthermic Typic Haplusterts										
Ap	0-19	0.76	33.27	65.98	clay	1.57	40.55	26.81	13.74	2.40
Bw	19-46	0.47	36.24	63.29	clay	1.61	39.49	25.91	13.58	2.05
Bss1	46-71	0.46	35.56	63.98	clay	1.64	38.83	25.14	13.69	1.68
Bss2	71-98	0.39	36.99	62.62	clay	1.65	37.39	24.60	12.79	1.34
Bss3	98-120	7.95	34.68	57.37	clay	1.62	35.32	23.08	12.24	0.82
Pedon 6 (Popatkhed): Very-fine, smectitic (calcareous), hyperthermic Vertic Haplustepts										
Ap	0-17	7.55	24.81	67.64	clay	1.62	43.39	29.19	14.20	1.39
Bw1	17-35	6.69	27.24	66.07	clay	1.57	41.57	28.84	12.73	0.67
Bw2	35-70	4.90	31.99	63.11	clay	1.53	38.94	25.91	13.03	0.84
Bw3	70-91	5.19	26.73	68.08	clay	1.50	43.92	29.46	14.46	0.55

Contd....

Horizon	Depth (cm)	Particle Size (%)			Textural Class	BD (Mg/m^3)	Water Retention (%)		AWC (%)	sHC (mm/hr)
		Sand	Silt	Clay			at 1/3 bar	at 15 bar		
AESR 10.2										
Pedon 7 (Paradi): Fine, smectitic (calcareous), hyperthermic Typic Haplusterts										
Ap	0-15	8.79	34.81	56.40	clay	1.36	30.60	17.45	13.15	5.01
Bw1	15-30	10.40	33.50	56.01	clay	1.45	30.07	17.72	12.35	2.48
Bw2	30-50	13.32	32.16	54.52	clay	1.53	28.32	16.08	12.24	2.11
Bss1	50-80	6.67	32.67	60.66	clay	1.47	32.12	18.04	14.08	1.79
Bss2	80-115	5.84	34.10	60.07	clay	1.52	32.07	17.72	14.35	1.70
Bss3	115-130	4.93	35.53	59.54	clay	1.47	31.90	17.26	14.64	0.78
Bss4	130-150+	5.36	34.22	60.42	clay	1.53	32.27	18.21	14.06	1.39
Pedon 8 (Mangli):Very-fine, smectitic (calcareous), hyperthermic Typic Haplusterts										
Ap	0-10	3.90	35.72	60.37	clay	1.47	32.12	21.91	10.21	4.23
Bw	10-30	2.45	40.43	57.12	clay	1.56	31.12	18.04	13.08	2.95
Bss1	30-50	2.28	36.61	61.11	clay	1.59	34.49	23.91	10.58	1.84
Bss2	50-80	0.48	33.64	65.88	clay	1.54	41.60	28.57	13.03	1.54
Bss3	80-110	0.45	35.19	64.37	clay	1.52	39.42	27.62	11.80	1.56
Bss4	110-140	0.51	34.22	65.26	clay	1.62	41.30	28.30	13.00	1.95
Pedon 9 (Waroda): Loamy, smectitic, hyperthermic Lithic Haplustepts										
Ap	0-10	33.16	30.73	36.11	clay loam	1.42	26.07	16.98	9.09	3.20
Bw	10-35	32.34	34.47	33.19	clay loam	1.36	24.42	15.83	8.59	3.46

Contd....

Horizon	Depth (cm)	Particle Size (%)			Textural Class	BD (Mg/m^3)	Water Retention (%)		AWC (%)	sHC (mm/hr)
		Sand	Silt	Clay			at 1/3 bar	at 15 bar		
Pedon 10 (Pevatha): Very-fine, smectitic, hyperthermic Vertic Haplustepts										
Ap	0-15	2.21	32.98	64.81	clay	1.57	39.46	27.84	11.62	3.44
Bw1	15-38	1.46	30.68	67.86	clay	1.48	42.60	29.57	13.03	2.98
Bw2	38-58	1.21	32.51	66.28	clay	1.36	42.37	29.62	12.75	2.58
Bw3	58-85	1.21	35.48	63.31	clay	1.49	38.12	26.98	11.14	1.80
Bk	85-108	3.02	34.17	62.81	clay	1.49	37.60	26.93	10.67	1.86
Pedon 11 (Asola): Clayey, smectitic (calcareous), hyperthermic Lithic Ustorthents										
Ap	0-15	13.44	22.13	64.44	clay	1.47	39.51	28.33	11.18	2.03
Pedon 12 (Shiva): Fine, smectitic (calcareous), hyperthermic Vertic Haplustepts										
Ap	0-10	13.37	19.92	66.71	clay	1.34	41.66	29.10	12.56	4.10
Bw1	10-38	12.61	28.81	58.58	clay	1.39	29.50	19.12	10.38	3.05
Bw2	38-59	11.14	28.33	60.54	clay	1.39	33.71	23.35	10.36	2.85
Bw3	59-82	11.35	26.86	61.79	Clay	1.46	34.01	22.74	11.27	3.16
Bw4	82-100	13.54	27.40	59.06	Clay	1.42	30.60	19.88	10.72	2.41
Bw5	100-150+	16.88	26.14	56.98	Clay	1.44	28.81	18.90	9.91	1.70

BD is an index of workability of soil, availability of soil moisture, aeration and root penetration. It has been reported that Vertisols may have BD values as high as 2.1 Mg m^{-3} (Dudal, 1965). The BD of Vertisols varies greatly because of their shrink-swell nature. Since shrink-swell phenomenon depends on soil moisture content, a change in moisture level changes BD values. In general, Vertisols have higher BD when they are dry and lower BD in a moist swollen stage. Depending on moisture content, the BD values are reported to vary from 1 to 2 Mg m^{-3} (Jewitt et al., 1979).

In AESR 6.3, the BD values (Table 4.2) of the pedons ranged from 1.48 to 1.72 Mg m^{-3} whereas in AESR 10.2, the BD values of the pedons ranged from 1.36 to 1.62 Mg m^{-3}. However, majority of the selected Vertisols had BD ≥1.4 Mg m^{-3} which might pose problem for root penetration. This unfavourable influence of BD appears to cause a decrease in abundance of roots with depth of soils. Despite this, Kadu et al. (2003) observed that in Vertisols of central India with a BD of >1.4, an optimum yield of cotton (18 q ha^{-1}) is generally obtained by farmers under rainfed conditions. The increase in bulk density is attributed to higher amount of expanding clays resulting in greater compactness in deep swelling clay soils (Rao et al., 1978). Increasing values of BD with depth, despite an increase in clay content, are due to compaction and the trend is common in Vertisols (Ahuja et al., 1989).

4.2.3 Saturated hydraulic conductivity (sHC)

Flux of soil water through profile is governed by sHC of soils which is influenced by texture, structure and moisture content of soils and thus affects crop growth as well.

In AESR 6.3, sHC (Table 4.2) of surface soils ranged from 1.34 to 3.23 mm hr^{-1} and in subsurface soils, it varied from 0.2 to 3.13 mm hr^{-1} in Pedons 1, 2, 3, 5 and 6. In case of pedon 4, which was from salt affected area of Purna Valley, Maharashtra, the sHC varied from 0.1 to 1.8 mm hr^{-1} and decreased with depth. This may be due to the increase in ESP with depth. Similar results were obtained by Balpande et al.

(1996) in Vertisols of the Purna Valley and Vaidya and Pal (2002) in Vertisols of central India. Kadu et al. (1993) also observed that the hydraulic conductivity values of Amravati and Akola districts range from <1 to 12 mm hr^{-1} with ESP ~ 6 and values of about 1 mm hr^{-1} indicate very poor internal drainage conditions; such conditions occur in soils even at an ESP value as low as 5.

In AESR 10.2, sHC of surface soils ranged from 2.03 to 5.01 mm hr^{-1} and decreased in subsurface and ranged from 0.78 to 3.16 mm hr^{-1}. The higher values in surface horizons are due to their porous nature as a result of regular tillage operations and relatively less clay content. Similar results were reported by Bharambe et al. (1986) in Jayakwadi and Purna command areas; Kadu (1991) in black soils of the Purna Valley; Nimkar et al. (1992) in soils of the Purna Valley and Kapse (2007) in shrink-swell soils of Maharashtra.

The decrease in sHC in subsurface soils may be due to increase in exchangeable Na percentage and ESP with depth. Similar results were obtained by Pal et al. (2000) in their study on arid and semi-arid regions of India and Kadu et al. (2003) in their study on semi-arid parts of central India.

The correlation studies indicate that the hydraulic conductivity had negative correlation with bulk density in AESR 6.3 (r= - 0.67) and AESR 10.2 (r= -0.69). Similar results were obtained by Padole et al. (1998[a]) who observed that hydraulic conductivity of soils was adversely affected by bulk density.

4.2.4 Water retention and available water capacity (AWC)

Water content under certain standard conditions is referred to as soil moisture constant. Soil water is the major component of soil in relation to plant growth. If the moisture content of a soil is optimum for plant growth, plants can readily absorb soil water. Not all water soils can hold is available to plants. Much of the water remains in the soil as thin film. But under field conditions, water content of soil is changing constantly with time and depth and is not static. Moisture retention

study was conducted at 33 kPa (field capacity) and 1500 kPa (wilting point) in each horizon of the pedons (Table 4.2).

In AESR 6.3, the moisture retention of pedons 1, 3, 4, 5 and 6 ranged from 28.55 to 44.07 percent at 33 kPa and from 17.36 to 29.46 percent at 1500 kPa. Pedon 2 had lower moisture retention as compared to above pedons and ranged from 22.01 to 27.60 percent at 33 kPa and 10.83 to 14.45 percent at 1500 kPa that might be due to less clay content in the pedon. The available water (AWC) ranged from 10.54 to 15.97 percent that increased gradually with clay content.

In AESR 10.2, the moisture retention of pedons (7, 8, 10, 11 and 12) ranged from 28.32 to 42.60 percent at 33 kPa and from 16.08 to 29.62 percent at 1500 kPa. Pedon 9 had low moisture retention as compared to above pedons which ranged from 24.42 to 26.07 percent at 33 kPa and 15.83 to 16.98 percent at 1500 kPa which may be due to less clay content. The available water (AWC) ranged from 8.59 to 14.64 percent that increased gradually with clay content. It is observed from the correlation studies between AWC and clay content that they had a positive relationship in AESR 6.3 (r= 0.60) and in AESR 10.2 (r=0.70).

Soil water retention is mainly dependent upon the amount and size of clay fractions and type of clay minerals. The black soils are dominated by smectite minerals in their clay fractions with large surface area which have the capacity to retain higher amount of water at different soil water suctions compared to other soils. A linear relationship between clay content and moisture retention was also reported by Padole et al. (1998[a]) in salt-affected Vertisols of Vidarbha region; Nagar et al. (1995) in different soil series in Chambal command area of Rajasthan; Nayak et al. (2004) in saline black soils of Gujarat state and Balpande et al. (2007) in Vertisols of the Purna Valley.

The moisture retention in pedon 4 (AESR 6.3) and pedon 7 (AESR 10.2) indicated that the sub-soils retain more moisture than the surface soils at all the given tensions. This may be due to slightly high

amount of clay and high concentration of Na in these layers. Balpande et al. (1996) in Vertisols of the Purna Valley; Kadu et al. (2003) in semi-arid parts of central India and Deshmukh (2009) in shrink-swell soil clays of Maharashtra reported that in soils with higher amount of Na^+ and Mg^{2+} in the exchange complex, the water held at 33 kPa may not be available to plants.

4.3 Chemical properties of soils

4.3.1 Soil reaction (pH)

pH is an important property of the soil as it determines salinity, alkalinity, nutrient availability, microbial activity and physical condition of soil. Soil reaction reflects the nature of parent material and climate, which determines soil composition. The pH values of the pedons are presented in table 4.3.

In AESR 6.3, the pedons 1, 3, 4 and 5 were moderately to strongly alkaline in nature and pH ranged from 8.0 to 8.8. The pedons 2 and 6 were moderately alkaline in nature and pH ranged from 8.0 to 8.3. In AESR 10.2, pH of pedons (7, 8, 10 and 12) were observed to be strongly alkaline in nature and pH ranged from 8.5 to 8.8. The pedons 9 and 11 were moderately alkaline in nature with pH 8.3. The pH of pedons increased with depth. Similar results were also reported by Pal et al. (2000[a]) who observed that in Vertisols, the pH in most cases increases with depth and becomes strongly alkaline in the subsurface.

4.3.2 Electrical conductivity (EC)

EC gives an insight about the presence of total soluble salts and is used as one of the criteria to differentiate between saline and non-saline soils. The data on electrical conductivity (at 25°C) presented in table 4.3 indicate that the soils of the study area were very low in soluble salt concentration.

The EC of the studied soils from both the AESRs ranged from 0.14 to 0.62 dSm^{-1} and showed an irregular trend with depth except in pedons 1 and 4. The variation of EC with depth might be due to differential leaching of salts from surface. The low range of EC in all the

pedons indicate that these soils are free from salt and hence they are responsive to fertilizers and management practices. The EC of pedons 1 and 4 varied from 0.16 to 1.11 dSm^{-1} and increased with depth. Kharche (1990) obtained similar results in Saongi watershed of Nagpur district and attributed the increase in EC with depth due to leaching of salts from surface to down below through percolating water followed by high evaporative demand resulting in the accumulation of salts in the subsurface horizons.

4.3.3 Organic carbon (OC)

Soil OC is considered to be the mainstay of soil quality. Soil OC is of prime importance for various plant nutrient cycles and influences soil colour, water retention, bulk density, susceptibility to erosion and soil structure (Rao and Manna, 2005). The significance of nature and content of clay as substrate has been stressed as the most important factor influencing OC dynamics. The organic carbon content is very important due to its favourable effect in improving the soil properties. The status of the organic carbon content depends on the source of organic material and its quality and its stage of degradation and decomposition.

The OC contents (Table 4.3) were low and, in general, a regular decrease in the level of organic carbon concentration has been observed down the profile. In AESR 6.3, it ranged from 0.20 to 0.64 per cent and in AESR 10.2, it ranged from 0.15 to 0.77 per cent. Vertisols generally have low organic matter due to low prevailing rainfall or aridity. Such a trend has also been reported in research findings of Velayutham et al. (2000) who observed that despite the addition of regular foliage and root accumulation as organic matter in soils, the organic carbon has not been improved due to semi-arid environment.

The OC contents in surface horizons of pedon 6 (0.91 per cent), pedon 7 (1.08 per cent) and pedon 11 (1.27 per cent) were found to be ~1, which may be due to addition of regular foliage and incorporation of organic manure. However, relatively recent investigations

(Bhattacharyya et al., 2003) indicate that there is an increasing trend of OC stock in black soils due to their continuous cropping with better management.

4.3.4 Calcium carbonate ($CaCO_3$)

Presence of 10% or more $CaCO_3$ in a soil classifies it as calcareous. Calcium not only improves the structure of soil but is also concerned with the decomposition of soil organic matter and synthesis of humus.

The $CaCO_3$ contents (Table 4.3) in the pedons of AESR 6.3 (except pedon 2) varied from 6.85 to 17.38 per cent. Pedon 2 was low in $CaCO_3$ that ranged from 4.7 to 5.4 percent. The $CaCO_3$ contents in the pedons of AESR 10.2 ranged from 4.83 to 13.3. Pedon 9 (AESR 10.2) was also low in $CaCO_3$ that ranged from 4.8 to 5.2 percent and showed irregular trend with depth. Most of the pedons (1, 3, 4, 7 and 8) showed violent to strong effervescences owing to calcareousness in soils. Pal et al. (2000[b]) attributed calcareousness in Vertisols due to the presence of both pedogenic and non-pedogenic $CaCO_3$ since both the forms react with HCl.

4.3.4 Cation exchange capacity (CEC)

CEC is an elucidative parameter for charge behaviour of the soils. The CEC values provide important information regarding ability of soils to supply certain nutrients to the plants and thus have strong influence on agricultural productivity. It is an indicator of the nutrient storage capacity of soils.

In AESR 6.3, CEC in the surface horizons of the pedons ranged from 45.2 to 60.1 cmol $(p^+)\,kg^{-1}$ and in sub soils, it ranged from 30.1 to 40.1 cmol $(p^+)\,kg^{-1}$ (Table 4.3). Pedon 2 was low in CEC that ranged from 24.8 to 29.9 cmol $(p^+)\,kg^{-1}$. This may be due to low clay percentage in this profile. In AESR 10.2, CEC in the surface soils of the pedons ranged from 47.6 to 65.9 cmol $(p^+)\,kg^{-1}$ and in sub soils, it ranged from 46.5 to 60.7 cmol $(p^+)\,kg^{-1}$. Pedon 9 was low in CEC that ranged from 32.8 to 35.6 cmol $(p^+)\,kg^{-1}$.

Table 4.3 Chemical properties of soils

Horizon	Depth (cm)	pH	Ec (dSm^{-1})	OC (%)	$CaCo_3$ (%)	Exchangeable cations				CEC	sum of bases	BS %	SAR	ESP	EMP
						Ca	Mg	Na	K						
						----------(cmol (p^+) kg^{-1})----------									
AESR 6.3															
Pedon 1 (Dongargaon): Fine, smectitic (calcareous), hyperthermic Typic Haplusterts															
Ap	0-17	8.5	0.16	0.54	8.38	37.1	15.2	0.7	0.7	53.1	53.7	101.2	0.63	1.31	28.70
Bw1	17-49	8.5	0.19	0.51	9.50	30.3	19.8	0.8	0.5	51.4	51.3	99.9	0.86	1.47	38.57
Bw2	49-84	8.8	0.28	0.37	9.63	23.1	23.5	1.3	0.4	48.9	48.3	98.7	1.86	2.67	48.05
Bss1	84-107	8.8	0.35	0.26	10.25	14.1	22.6	2.3	0.4	40.0	39.5	98.7	4.19	5.86	56.51
Bss2	107-150+	8.8	0.56	0.20	10.50	11.1	17.6	2.8	0.4	30.1	31.9	106.1	4.95	9.22	58.57
Pedon 2 (Sonori): Loamy, smectitic, hyperthermic Lithic Haplustepts															
Ap	0-19	8.1	0.34	0.47	5.40	19.8	11.3	0.8	1.0	29.9	32.8	109.8	0.84	2.62	37.64
Bw	19-43	8.3	0.19	0.35	4.75	14.2	13.2	0.6	0.3	24.8	28.3	114.0	0.82	2.41	53.26
Pedon 3 (Mana): Fine, smectitic (calcareous), hyperthermic Typic Haplusterts															
Ap	0-15	8.5	0.14	0.41	14.25	39.4	10.4	0.7	1.2	49.6	51.7	104.1	0.50	1.40	20.95
Bw	15-45	8.5	0.14	0.32	14.25	35.1	12.7	0.6	0.8	47.0	49.2	104.8	0.52	1.31	27.06
Bss1	45-83	8.5	0.15	0.29	14.75	37.7	14.9	0.7	0.7	48.7	54.0	110.8	0.58	1.35	30.52
Bss2	83-150+	8.5	0.20	0.29	17.38	32.1	14.7	0.7	0.7	49.6	48.2	97.1	0.67	1.42	29.60

Contd....

Horizon	Depth (cm)	pH	Ec (dSm^{-1})	OC (%)	$CaCo_3$ (%)	Exchangeable cations				CEC	sum of bases	BS %	SAR	ESP	EMP
						Ca	Mg	Na	K						
						----------(cmol (p^+) kg^{-1})----------									
Pedon 4 (Vallabhanagar): Very-fine, smectitic (sodic), hyperthermic Typic Haplusterts															
Ap	0-19	8.5	0.16	0.50	10.28	31.7	16.1	0.7	0.7	45.2	49.3	109.0	0.74	1.63	35.60
Bw1	19-46	8.6	0.25	0.49	9.70	24.7	19.6	1.6	0.6	40.9	46.4	113.6	1.97	3.83	47.88
Bw2	46-71	8.7	0.31	0.41	11.63	23.1	20.2	3.0	0.6	40.4	46.9	116.1	4.01	7.51	50.00
Bss1	71-98	8.8	0.48	0.43	8.08	24.8	21.1	4.9	0.6	51.4	51.5	100.3	6.44	9.62	41.12
Bss2	98-120	8.7	0.84	0.41	7.28	29.6	20.6	5.7	0.6	55.7	56.6	101.5	6.75	10.26	37.00
Bss3	120-143	8.7	1.11	0.41	6.85	25.6	22.5	6.3	0.7	48.7	55.2	113.2	8.40	12.98	46.26
Pedon 5 (Rohana): Very-fine, smectitic (calcareous,) hyperthermic Typic Haplusterts															
Ap	0-19	8.2	0.23	0.64	12.25	42.4	11.6	0.7	1.3	47.0	56.1	119.4	0.55	1.57	24.73
Bw	19-46	8.4	0.19	0.47	10.88	44.7	14.4	0.6	0.6	54.9	60.3	110.0	0.46	1.04	26.24
Bss1	46-71	8.4	0.23	0.40	9.75	41.5	17.6	0.8	0.7	52.2	60.5	115.9	0.72	1.50	33.61
Bss2	71-98	8.5	0.26	0.38	9.38	33.3	21.2	1.4	0.6	52.2	56.6	108.3	1.57	2.66	40.61
Bss3	98-120	8.6	0.23	0.38	8.63	31.6	21.6	1.6	0.7	55.7	55.4	99.4	1.83	2.80	38.69
Pedon 6 (Popatkhed): Very-fine, smectitic (calcareous), hyperthermic Vertic Haplustepts															
Ap	0-17	8.1	0.20	0.91	6.48	51.2	11.7	0.9	1.3	60.1	65.1	108.3	0.59	1.45	19.39
Bw1	17-35	8.1	0.18	0.69	5.93	49.3	12.0	0.7	0.6	58.6	62.7	106.9	0.48	1.18	20.54
Bw2	35-70	8.1	0.17	0.67	6.55	47.8	19.6	0.6	0.5	59.2	60.5	102.3	0.43	1.04	19.68
Bw3	70-91	8.0	0.23	0.69	5.48	44.5	21.8	0.6	0.5	57.4	57.7	100.5	0.47	1.12	20.97

Contd....

Horizon	Depth (cm)	pH	Ec (dSm^{-1})	OC (%)	$CaCo_3$ (%)	Exchangeable cations				CEC	sum of bases	BS %	SAR	ESP	EMP
						Ca	Mg	Na	K						
						----------(cmol (p^+) kg^{-1})----------									
AESR 10.2															
Pedon 7 (Paradi): Fine, smectitic (calcareous), hyperthermic Typic Haplusterts															
Ap	0-15	8.7	0.62	1.08	7.88	32.4	15.1	1.6	2.3	49.6	51.4	103.7	1.59	3.33	30.37
Bw1	15-30	8.7	0.15	0.49	7.98	31.1	14.9	0.7	0.4	46.5	47.1	101.2	0.69	1.51	32.04
Bw2	30-50	8.7	0.17	0.37	8.55	33.8	15.5	0.7	0.3	49.6	50.3	101.3	0.69	1.45	31.19
Bss1	50-80	8.7	0.17	0.29	9.10	32.8	15.4	0.8	0.3	48.9	49.3	100.7	0.76	1.60	31.49
Bss2	80-115	8.8	0.15	0.38	11.23	33.5	17.6	1.0	0.3	53.7	52.4	97.7	1.07	1.94	32.77
Bss3	115-130	8.7	0.18	0.41	12.93	31.6	19.8	1.2	0.3	54.9	53.0	96.5	1.36	2.22	36.10
Bss4	130-150+	8.7	0.20	0.33	13.30	30.1	21.6	1.1	0.3	54.9	53.2	96.9	1.35	2.06	39.38
Pedon 8 (Mangli):Very-fine, smectitic (calcareous), hyperthermic Typic Haplusterts															
Ap	0-10	8.4	0.31	0.77	8.20	37.9	11.3	1.0	1.7	47.6	51.8	108.9	0.74	2.01	23.64
Bw	10-30..	8.6	0.16	0.57	8.48	37.2	11.9	0.6	1.0	50.4	50.8	100.7	0.49	1.22	23.62
Bss1	30-50	8.6	0.17	0.37	9.08	36.7	13.5	0.5	0.7	51.4	51.4	100.1	0.42	0.96	26.36
Bss2	50-80	8.6	0.20	0.28	10.63	33.5	23.4	0.5	0.5	54.1	57.9	107.1	0.59	0.93	43.27
Bss3	80-110	8.6	0.24	0.22	11.70	30.1	27.9	0.6	0.6	55.7	59.2	106.2	0.80	1.06	50.11
Bss4	110-140	8.7	0.24	0.15	12.03	24.2	28.7	0.7	0.6	54.0	54.2	100.4	1.01	1.22	53.21
Pedon 9 (Waroda): Loamy, smectitic, hyperthermic Lithic Haplustepts															
Ap	0-10	8.3	0.22	0.40	4.80	23.6	11.4	0.7	0.9	35.6	36.6	102.9	0.70	2.00	32.08
Bw	10-35	8.3	0.44	0.43	5.20	21.9	11.6	0.9	1.3	32.8	35.7	108.9	0.90	2.65	35.41

Contd....

Horizon	Depth (cm)	pH	Ec (dSm^{-1})	OC (%)	$CaCo_3$ (%)	Exchangeable cations				CEC	sum of bases	BS %	SAR	ESP	EMP
						Ca	Mg	Na	K						
						----------(cmol (p^+) kg^{-1})----------									
Pedon 10 (Pevatha): Very fine, smectitic, hyperthermic Vertic Haplustepts															
Ap	0-15	8.6	0.15	0.50	4.83	51.8	7.4	0.5	0.8	54.9	60.6	110.4	0.29	1.00	13.44
Bw1	15-38	8.5	0.14	0.37	5.43	49.0	9.5	0.4	0.4	54.9	59.3	108.1	0.24	0.71	17.32
Bw2	38-58	8.5	0.18	0.40	5.55	48.9	11.9	0.4	0.4	55.7	61.6	110.6	0.28	0.73	21.29
Bw3	58-85	8.6	0.19	0.34	8.08	43.2	12.8	0.4	0.4	54.9	56.8	103.5	0.33	0.77	23.30
Bk	85-108	8.6	0.21	0.22	11.68	42.2	13.7	0.4	0.4	52.2	56.8	108.7	0.35	0.83	26.32
Pedon 11 (Asola): Clayey, smectitic (calcareous), hyperthermic Lithic Ustorthents															
Ap	0-15	8.3	0.53	1.27	12.15	53.5	8.8	0.7	0.9	59.2	63.9	108.0	0.42	1.24	14.90
Pedon 12 (Shiva): Fine, smectitic (calcareous), hyperthermic Vertic Haplustepts															
Ap	0-10	8.4	0.25	0.77	6.90	57.9	6.2	0.9	1.0	65.9	66.0	100.2	0.40	1.32	9.41
Bw1	10-38	8.6	0.15	0.54	7.60	53.6	12.5	0.7	0.5	57.6	67.2	116.7	0.46	1.16	21.67
Bw2	38-59	8.6	0.17	0.46	7.18	52.2	14.8	0.6	0.3	59.5	68.0	114.3	0.47	1.05	24.91
Bw3	59-82	8.5	0.15	0.41	8.45	51.6	16.1	0.6	0.3	60.7	68.7	113.1	0.51	1.06	26.54
Bw4	82-100	8.5	0.19	0.41	8.28	48.0	17.6	0.7	0.3	58.6	66.5	113.5	0.57	1.14	29.95
Bw5	100-150+	8.6	0.20	0.47	10.13	40.3	19.1	0.7	0.3	54.2	60.4	111.3	0.69	1.31	35.20

According to Brady (1974), the CEC of the soils mainly depends on the amount and nature of clay, organic matter and pH. The correlation studies indicate that the CEC of soils had significant positive correlation with clay in AESR 6.3 (r=0.92) and AESR 10.2 (r=0.94) at 5 % level. The high CEC in black soils is attributed to the high clay content and the presence of smectite minerals. Similar observations were made by Dudal (1965) in black soils of tropical and subtropical regions in Texas; Nimkar et al. (1992) in shrink-swell soils of the Purna Valley, Balpande et al. (1996) in Vertisols of the Purna Valley and Nayak et al. (2004) in saline black soils of Gujarat.

4.3.5 Exchangeable cations and base saturation of soils

Table 4.3 presents data on exchangeable cations (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}) and base saturation of the pedons. Exchangeable cations give an idea about exchange phenomena of soils. Data presented in the table 4.3 indicate that exchangeable Ca was relatively high in pedons of both the AESRs. In AESR 6.3, it ranged from 11.1 to 51.2 cmol (p^{+}) $kg^{-1}$and in AESR 10.2, it ranged from 21.9 to 57.9 cmol (p^{+}) kg^{-1} and decreased with depth. Exchangeable Mg was relatively high in soils of both the AESRs. In AESR 6.3, it ranged from 10.4 to 23.5 cmol (p^{+}) kg^{-1} and in AESR 10.2, it ranged from 6.2 to 28.7 and increased with depth which might be due to higher solubility of sodium and magnesium salts resulting in their leaching down the profile. Similar results were obtained by Krishnamoorthy and Govindarajan (1977) in associated red and black soils of Andhra Pradesh.

Exchangeable Na was, in general, low in pedons of both the AESRs. In the pedons of AESR 6.3 (except pedon 4), it ranged from 0.6 to 2.8 cmol (p^{+}) kg^{-1} and in pedon 4, it ranged from 0.7 to 6.3 cmol (p^{+}) kg^{-1}. In all the pedons of AESR 10.2, it ranged from 0.4 to 1.6 cmol (p^{+}) kg^{-1} and increased with depth except in pedons 7 and 8 which showed irregular trend. Data indicate that exchangeable K was relatively low in all the pedons of both the AESRs. It ranged from 0.3 to 1.3 cmol (p^{+}) kg^{-1} in AESR 6.3 and from 0.3 to 2.3 cmol (p^{+}) kg^{-1} in AESR 10.2 and decreased with depth.

The base saturation of these soils varied from 97.1 to 113.2 percent in AESR 6.3 and from 96.5 to 116.7 percent in AESR 10.2. Base saturation per cent in excess of 100 suggests the presence of zeolites (Bhattacharyya et al., 1993; Pal et al., 2006) who reported such findings in Vertisols of Western Ghats and in Vertisols of Peninsular India.

The data showed that clay is dominantly saturated with Ca followed by Mg, Na and K. Calcium was the dominant exchangeable cation followed by magnesium, sodium and potassium indicating presence of calcium bearing minerals in parent rocks. Similar results were reported by Maji et al. (2005) in soils of basaltic terrain in sub-humid tropics of central India.

Exchangeable sodium percent (ESP) in the pedons of AESR 6.3 (except P4) ranged from 1.04 to 9.2 and in P4, it ranged from 1.63 to 12.98 percent. In the pedons of AESR 10.2, it ranged from 0.71 to 3.33. In AESR 6.3, ESP increased with depth which may be due to accelerated rate of formation and accumulation of pedogenic calcium carbonate in arid climate. Similar results were observed by Kadu et al. (1993) in shrink-swell soils of the Purna Valley.

Exchangeable magnesium percent (EMP) of the pedons in AESR 6.3 ranged from 19.3 to 58.5 and in AESR 10.2, it ranged from 9.4 to 53.2 percent. Sodium adsorption ratio (SAR) of the pedons in AESR 6.3 (except pedon 4) ranged from 0.43 to 4.95 and SAR of pedon 4 ranged from 0.74 to 8.4. In AESR 10.2, SAR of the pedons ranged from 0.24 to 1.59. In soils of both the AESRs, EMP and SAR increased with depth which could be due to relative decrease of Ca ions in soil solution due to their precipitation as $CaCO_3$. Similar results were obtained by Pal et al. (2000^b) in soils of arid and semi-arid regions of India who opined that the enhancement of ESP and EMP is related to the relative decrease of Ca ions in soil solution due to precipitation of Ca ions as $CaCO_3$.

In case of Pedon 4, both ESP (1.63 to 12.98) and SAR (0.74 to 8.4) increased with depth. sHC ranged from 0.1 to 1.82 mm/hr which indicates very poor internal drainage conditions. Such conditions occur in similar soils even at an ESP value as low as 5 (Kadu et al., 1993). Thus an ESP of 5 should be used as the lower limit for sodic subgroups of Vertisols, as suggested earlier (Balpande et al. 1996), rather than an ESP of 15 as given in Soil Taxonomy (Soil Survey Staff 1994). Accordingly, pedon 4 was considered as a sodic subgroup of Vertisols.

4.4 Nutrient status of soils

4.4.1 Available macronutrients (nitrogen, phosphorus and potassium)

Nutrients play an important role in crop production. The horizon wise data on major macronutrients N (nitrogen), P (phosphorus) and K (potassium) was determined for each profile. It was classified into different ratings (low, medium and high) given as per ICAR (2006) at 0-20 cm soil depth and is presented in table 4.4.

In AESR 6.3, the available N was found to be low in all the soils and ranged from 163.1 to 187.3 kg/ha. The available P content was low in the P1, P2, P3, P4 and P5 that ranged from 3.5 to 11.2 kg/ha and medium in P6 (19.6 kg/ha). The available K content, was found to be high in all the soils that ranged from 412.2 to 456.2 kg/ha. In AESR 10.2, the available N was found to be low in all the soils and ranged from 138.9 to 195.7 kg/ha. The available P content was low in P10 (6.2 kg/ha) and medium in P7, P8, P9, P11 and P12 that ranged from 13.9 to 22.3 kg/ha. The available K content was high in all the soils of AESR 10.2 and ranged from 375.0 to 535.3 kg/ha.

Table 4.4 Available nutrient status of soils

Available Nitrogen (kg/ha)			Available Phosphorus (kg/ha)			Available Potassium (kg/ha)		
Low	Medium	High	Low	Medium	High	Low	Medium	High
AESR 6.3 (0-20 cm depth)								
P1 (175.6) P2 (163.1) P3 (172.8) P4 (163.1) P5 (175.6) P6 (187.3)	-	-	P1 (4.1) P2 (8.3) P3 (5.6) P4 (3.5) P5 (11.2)	P6 (19.6)	-	-	-	P1 (412.2) P2 (437.0) P3 (474.2) P4 (424.6) P5 (456.2) P6 (511.4)
AESR 10.2 (0-20 cm depth)								
P7 (188.0) P8 (138.9) P9 (175.9) P10 (184.5) P11 (195.7) P12 (175.6)	-	-	P 10 (6.2)	P7(19.5) P8 (15.1) P9 (22.3) P11 (13.9) P12 (14.6)	-	-	-	P7 (535.3) P8 (460.9) P9 (437.0) P10 (375.0) P11 (437.0) P12 (424.6)

Rating of nutrients (ICAR, 2006)			
Particulars	**Low**	**Medium**	**High**
Nitrogen (kg/ha)	<280	280-560	>560
Phosphorus (kg/ha)	<12.5	12.5-25	>25
Potassium (kg/ha)	<135	135-335	>335

4.4.2 DTPA extractable micronutrients (Fe, Mn, Zn and Cu)

The term 'micronutrients' denote the elements which are essential for plants but are required in small amounts. The main source of micronutrients in soil is the parent material or rocks from which the soils have been formed.

The status of the micronutrients at various depths viz., 0-20 cm, 20-40 cm, 40-60 cm, 60-80 cm and 80-100 cm presented graphically and observed that DTPA-extractable micronutrients viz., iron (Fig 4.1), zinc (Fig 4.2), manganese (Fig 4.3) and copper (Fig 4.4) were found to decrease with depth (from 0-100 cm) in soils of both the AESRs.

The study indicate that soils were low to medium in iron content and manganese content; high in copper content and low to deficient in zinc content (Annexure II). Due to introduction of high yielding varieties, extension of areas under irrigation and use of high NPK fertilizers, particularly under intensively cultivated lands, deficiencies of micronutrients have been on the rise in India over the past four decades (Katyal and Rattan, 1995).

4.5 Biological properties of soils

Soil health has been defined as the capacity of a soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality and promote plant and animal health (Doran et al., 1996). Sustainability of agricultural systems has become an important issue all over the world. Many issues of sustainability are related to soil quality and its change with time (Karlen et al., 1997). There is a surge of interest in soil quality assessment through measurement of various physical, chemical and biological attributes that are sensitive to soil management. Assessing landuse-induced changes in soil properties is essential for addressing the issue of agro-ecosystem transformation and sustainable land productivity. Soil biological parameters have been suggested as important indicators of soil quality (Dick, 1994). It has been proposed that the microbiological and biochemical status of a soil can be used as an early and sensitive

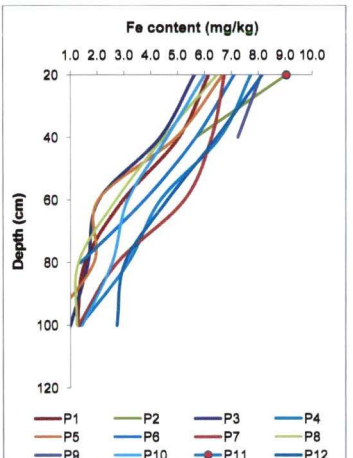


Fig. 4.1 Fe content in pedons

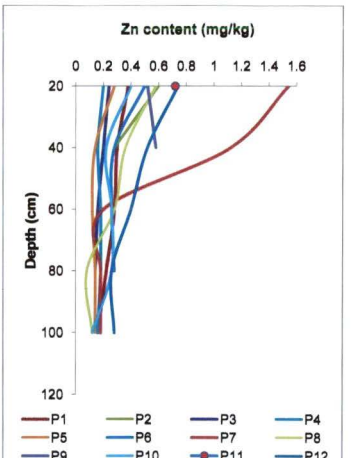


Fig. 4.2 Zn content in pedons

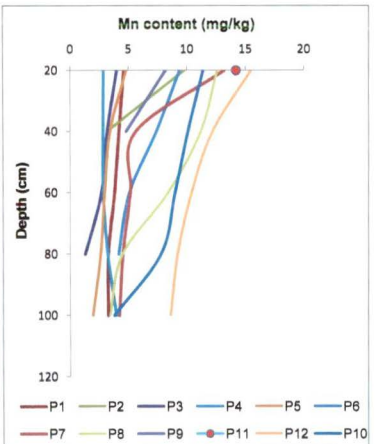


Fig. 4.3 Mn content in pedons

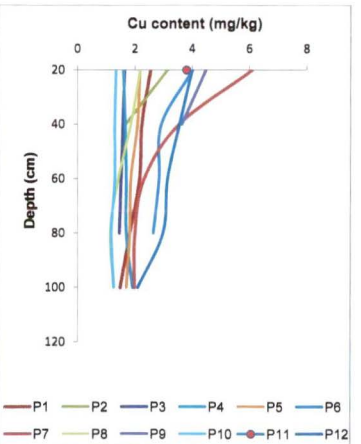


Fig. 4.4 Cu content in pedons

indicator of soil ecological stress or restoration processes in both natural and agro-ecosystems (Bolton et al., 1985; Ruf et al., 2003).

Soil organisms act as primary driving agent of nutrient cycling, regulating the dynamics of soil organic matter, soil carbon sequestration and greenhouse gas emissions, modifying soil structure and water regimes, enhancing the amount of nutrient acquisition by vegetation, conferring stress tolerance, resisting pathogens and improving plant health. Physical and chemical properties are shaped by biological activity and biological activity is enhanced or limited by chemical and physical conditions. A large, diverse, and active population of soil organisms may be the most important indicator of a healthy soil (Rao, 2007). The information generated on soil microbial attributes through this study will enrich Indian soil information system which will be highly useful for the assessment of soil/land quality and the changes in the soil quality indicators for sustainable land resource management.

Most of the microbial activities take place around the root zones (Hiltner, 1904) and are restricted within 0-30 cm soil depth and thus the biological properties of the studied soils were determined for soil depth 0-30 cm which are discussed as below.

4.5.1 Soil microbial biomass carbon (SMBC)

Soil microbial biomass carbon represents the fraction of soil responsible for the energy and nutrient cycling and regulation of organic matter transformations (Sparling 1997). Microbial biomass measurements have been used to estimate the biological status of soil. Such measurements give an estimate of the activity or total mass of microbial population and have been successful in comparing soil systems.

SMBC is one of the most promising indicators of soil quality because it responds promptly to environmental changes, often much earlier than physical and chemical parameters (Alvarez and Alvarez, 2000; Franchini et al., 2007; Hungria et al., 2009; Kaschuk et al.,

2010). Soil microbial biomass is a source and sink of soil nutrients (Hernot and Robertson, 1994) and the measurement of microbial biomass is useful for describing biomass turnover in different ecosystems (Solaiman, 2007).

The SMBC (Table 4.5) of all the soils in both the AESRs varied significantly at 5% level (Fig. 4.5). This may be due to poor availability of resources such as organic matter. In AESR 6.3, among the six soils, the highest SMBC (157.55 μg g^{-1}) was recorded in P6 whereas the lowest SMBC was recorded in P3 (40.97 μg g^{-1}). In AESR 10.2, the highest SMBC was recorded in P12 (157.78 μg g^{-1}) and lowest in P7 (37.97 μg g^{-1}). Similar results were observed by Wardle (1992). Bardgett and Shine (1999) who reported that differences in soil microbial biomass were due to gradients in resource availability, in particular, soil organic matter. Soil microbiological properties such as microbial biomass may be used as early and sensitive indicators of soil quality (Bending et al., 2004). Li and Sarah (2003) reported significant decrease of microbial biomass with the increasing aridity along a climatic transect in Judean Desert of Israel. Insam (1990) who studied microbial biomass carbon along a climatic transect in North America also concluded that the ratio of precipitation and evaporation affects the soil microbial activity and microbial biomass. Omer and Ilyas (2008) in the studies conducted in Bartn Province, Turky reported negative correlation between SMBC and soil pH.

The pooled comparisons of SMBC in both the AESRs indicated that the SMBC was higher in AESR 10.2 (37.97 to 157.78 μg g^{-1}) than that in AESR 6.3 (40.97 to 157.55 μg g^{-1}). This may be due to increasing aridity as the average SMBC in different bio-climates decreased in the order, sub-humid dry (SHd) > sub-humid moist (SHm) > semi-arid dry (Sad) > arid.

In AESR 6.3, SMBC showed negative correlation with pH (r= -0.58), ESP (r= -0.27) and EMP (r= -0.55). In case of AESR 10.2, there was negative correlation of SMBC with pH (r=-0.48), ESP (r=-0.40) and EMP (r=-0.44).

Some authors suggest that maximum activities of soil microbial biomass occur at pH values of about 6.5 (Tabatabai, 1994). Mummey et al. (2002) also showed variability in microbial biomass that was attributed to alterations in soil pH. Soils under crop rotations with high input and diversity of organic materials are reported to contain higher concentrations of microbial biomass and enzymes compared with mono-cropping systems (Friedel et al., 1996; Moore et al., 2000).

4.5.2 Dehydrogenase activity (DHA)

Soil DHA reflects the total range of oxidative activity of soil microflora and consequently it may be a good indicator of microbiological activity in soil (Skujins, 1973 and 1976). Among various soil enzymes, dehydrogenase activity (DHA) has been recognised as an important biochemical indicator in soil (Gagnon et al., 2007 and Ryoichi and Senaratne, 2009). Among microbiological and biochemical factors, soil enzymes have been suggested as potential indicators of soil quality due to their biological nature, simple measurement and rapid response to changes in soil management when compared to other biological properties (Tabatabai, 1994; Fließbach et al., 2007; Hojati and Nourbakhsh 2009; Ling, 2010). Among various soil enzymes, dehydrogenase activity (DHA) has been recognised as important biochemical indicators in soil (Gagnon et al. 2007; Ryoichi and Senaratne, 2009).

The DHA (Table 4.5) of all the soils in both the AESRs varied significantly at 5 % level (Fig 4.6). In AESR 6.3, among the six soils, highest DHA (2.98 µg TPF g^{-1}) was recorded in P1 whereas the lowest DHA (1.81 µg TPF g^{-1}) was recorded in P6. The low level of DHA may be due to the alkaline nature of soils. Similar results were observed by Rao and Ghai (1985). In our study, DHA was found to be negatively correlated with organic carbon (r= -0.55) which was contradictory to the findings of Bergstrom et al. (1998) and Roldan et al. (2005). DHA was positively correlated with pH (r=0.49) in AESR 6.3. Similar results were observed by Von Mersi and Schinner (1991) and Brzezinska et al.

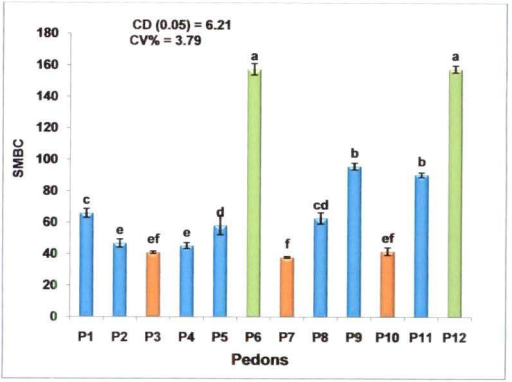


Fig. 4.5 Soil microbial biomass carbon (SMBC)

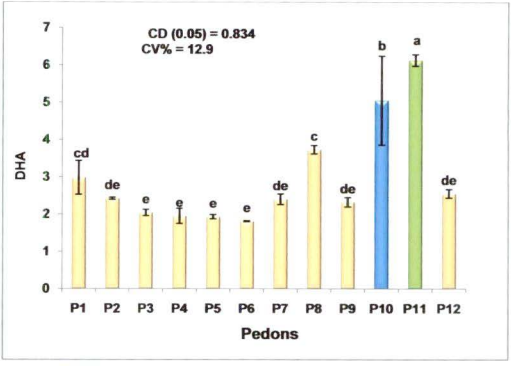


Fig. 4.6 Soil dehydrogenase activity (DHA)

(Error bars (±SD) with the same letter are not significantly different (α 0.05))

(2001) who reported that DHA was enhanced by increasing the pH of soil system.

In AESR 10.2, the highest DHA (6.13 µg TPF g^{-1}) was recorded in P11 whereas the lowest DHA was recorded in P9 (2.32 µg TPF g^{-1}). DHA was found to be positively correlated with organic carbon (r= 0.35). DHA in soil depends on the content of soluble organic carbon as also evidenced by enhanced soil enzyme activities as a result of increased organic carbon in the surface soil horizon. Similar results were obtained by Bergstrom et al. (1998) and Roldan et al. (2005) who also observed a positive correlation between soil organic matter and enzyme activities. The enzyme activity was also positively correlated with clay percent (r=0.59). Similar results were obtained by Beyer et al. (1992) who also observed a positive correlation between clay content and enzyme activity (DHA) in arable soils of Northwest Germany. Soil micropores protect mineralising microorganisms against grazers (Killham, 1994) and this can be one of the reasons for the higher microbial biomass and enzyme activity of the fine-textured soils.

In case of P11 (AESR 10.2), the higher DHA may be due to litter-fall or high input of organic manure. The litter-fall inputs favour the overall soil oxidative activity as the litter-fall undergoes decomposition, smaller and simpler organic molecules are leached down from the litter layer to the surface soil horizon as water-soluble organic matter thus providing a labile organic substrate for soil microorganisms and better enzyme activities. Similar results were reported by Gorres et al. (1998). The major reason for increased DHA in the surface soil is attributed to the greater availability of organic carbon, nutrients and stimulated microbial activity in the surface soil (Casida, 1977; Zaman et al., 2002). However, DHA was also reported to vary strongly in the surface horizon of soil and this behaviour did not correspond with the spatial distribution of other properties (Piotrowska et al., 2011). Dehydrogenase activity has been widely used as a generalized comparative index of microbial activity but it has not always been consistently correlated with microbial activity (Rao and Manna, 2005).

Table 4.5 Biological properties of soils

Pedon No	SMBC (µg/g)	DHA (µg TPF g^{-1})	Soil respiration (mg /g)	Particulate organic Matter (%)	Nitrogen Mineralisation (kg /ha)
AESR 6.3					
P1	65.92	2.98	0.91	3.25	22.82
P2	46.76	2.42	1.08	1.90	12.54
P3	40.97	2.04	1.10	0.85	18.82
P4	45.29	1.95	0.85	2.57	14.54
P5	58.22	1.93	0.94	2.92	26.27
P6	157.55	1.81	0.36	3.15	32.27
AESR 10.2					
P7	37.97	2.40	0.42	0.36	25.09
P8	62.90	3.73	2.87	2.20	38.99
P9	95.87	2.32	1.93	1.38	13.82
P10	41.86	5.05	0.46	0.66	25.68
P11	90.49	6.13	3.68	2.29	16.27
P12	157.78	2.55	1.28	5.07	32.72
CD (0.05)	6.21	0.83	0.78	0.35	4.33
CV %	3.79	12.9	27	7.3	8.5

Overall, the DHA was found to be more in sub-humid climate (AESR 10.2) as compared to the hot moist semi-arid climate (AESR 6.3). The decreased DHA in AESR 6.3 could be attributed to aridity. Similar results were observed by Li and Sarah (2003), who reported significant decrease of DHA with increasing aridity along a climatic transect in Judean Desert of Israel. DHA of soils was positively correlated with CO_2 in AESR 6.3 (r=0.38) and AESR 10.2 (r=0.47). Generally, the rate of CO_2 emission was higher in the soils developed from clays and loams, which shows a significant positive relationship between CO_2 production and DHA in the incubated soils (Dendooven et al., 1996).

The maximum DHA was recorded in the surface horizon (0-15 cm) and almost 50% of DHA activities was found to be restricted within 0-30 cm soil depth. The average dehydrogenase activity in different bioclimates were in decreasing order of sub-humid moist>semi-arid dry>sub-humid dry> arid, whereas its activities in different cropping systems were in decreasing order of legume>cereals>cotton> sugarcane (Velmourougane et al., 2013).

4.5.3 Soil respiration (CO_2 mineralisation)

Soil respiration is an evaluation of soil biological activity and extent of organic matter decomposition. Microbial respiration is most important both at agricultural and environmental level. This parameter indicates the oxidative capacity of soil microorganisms and, therefore, is influenced both by the energy sources that are in the soil and the number of microorganisms. Respiration activity has been frequently used to evaluate soil quality, soil fertility or soil contamination with organic pollutants or heavy metals and for the evaluation of the effect of the change in land use (Brookes, 1995). Soil respiration gives estimates of decomposition activity and carbon fertility of a soil (Rao, 2007). It may vary with several factors, such as climate, soil management practices, amendments, contaminations, etc. The fact that it may be coupled with the use of different energy sources

(induced respiration) may reflect the microbial potentiality of this parameter.

The rate of soil respiration (Table 4.5) of all the pedons in both the AESRs varied significantly at 5% level (Fig. 4.7). In AESR 6.3, among the six pedons, the highest respiration rate was observed in P3 (1.10 mg/g) whereas the lowest rate was in P6 (0.36 mg/g). In AESR 10.2, the highest respiration rate was recorded in P11 (3.68 mg/g) whereas lowest respiration rate was in P7 (0.42 mg/g).

Soil respiration was positively correlated with dehydrogenase activity of soils in both the AESRs [AESR 6.3 (r=0.38) and in AESR 10.2 (r= 0.47)]. Similar observations were reported by Dendooven et al. (1996) in their enzyme dynamics studies in soils of Norway.

4.5.4 Nitrogen mineralization

Mineralizable nitrogen indicates the potential of nitrogen fertility and effects of stress on the system. Nitrifier population, being a key group in the nitrogen cycle, is very sensitive to environmental stress and, therefore, may be a group of interest in soil quality assessment.

Nitrate-N (NO_3-N) reflects the residual effects of crop management practices including crop rotation, fertilization strategies, and use of animal manure. It provides insight regarding the potential for leaching and contamination of groundwater or surface water sources and for nitrous oxide (NO_2) emissions (Rice et al., 1996 and Allan and Killorn, 1996).

The rate of N mineralization in different soils is presented in table 4.5 and varies significantly at 5% level in both the AESRs as shown in fig. 4.8. In AESR 6.3, the rate of N mineralization was the highest in P6 (32.27 kg/ha) and the lowest was recorded in P2 (12.54 kg/ha). In AESR 10.2, the rate of mineralization was the highest in P8 (38.99 kg/ha) whereas it was the lowest in P9 (13.82 kg/ha). Mineralizable nitrogen was not significantly correlated with soil chemical parameters. The rate of nitrogen mineralization had positive correlation with clay percent in AESR 6.3 (r= 0.60) as well as in AESR

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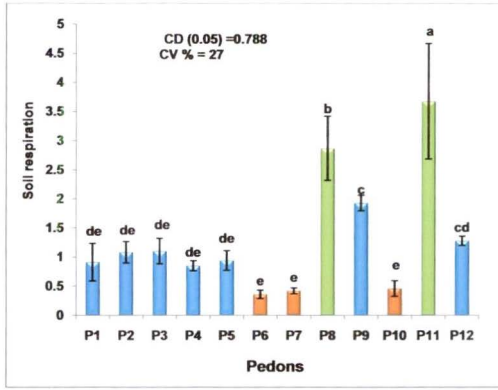


Fig.4.7 Soil respiration (Carbon mineralization)

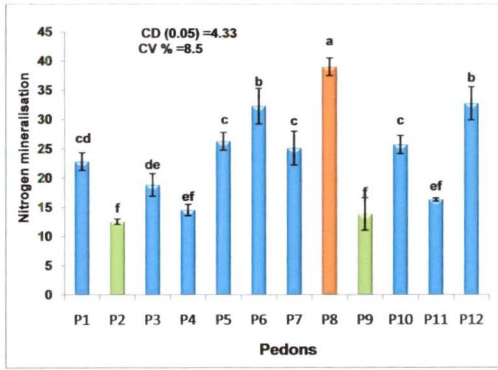


Fig.4.8 Nitrogen mineralisation

(Error bars (±SD) with the same letter are not significantly different (α 0.05))

10.2 (r= 0.52). This was contradictory to the findings of Cote et al. (2000) who observed negative correlation between clay content and N mineralization.

4.5.5 Particulate organic matter (POM)

POM, >53 mm, represents a significant proportion of the slow pool of SOM and it is important for maintaining the stability of macro-aggregates (>250mm). POM is considered as a biologically active fraction of SOM and is a sensitive indicator of management-induced changes in the fate of crop residues and the turnover of SOM constituents (Rao, 2007).

As perhaps the most easily decomposable fraction of nonliving SOM after microbial biomass, POM fulfils many soil functions mediated by OM. It is a source of food/energy for microorganisms and soil animals as well as nutrients for plant growth. POM enhances aggregate stability, water infiltration and soil aeration. It inceases cation exchange capacity and pH. It also binds environmental pollutants such as heavy metals and pesticides. POM may play an important role in the suppression of soil borne diseases (e.g. damping off of cucumber) when applied as compost. This may be explained by the fact that POM is an important source of food/energy in the compost for microorganisms responsible for disease suppression (Rao and Manna, 2005).

POM contents in different soils are presented in table 4.5 which vary significantly at 5% level (Fig 4.9) in both the AESRs. In AESR 6.3, the POM content was the highest in P1 (3.25 %) whereas the lowest was recorded in P3 (0.85%). In AESR 10.2, POM was the highest in P12 (5.07%) and the lowest was recorded in P7 (0.36%). A positive correlation between POM and N mineralization was observed in AESR 6.3 (r= 0.58) and AESR 10.2 (r= 0.36). POM had also a positive correlation with organic carbon in AESR 6.3 (r= 0.62) and in AESR 10.2 (r= 0.32). The variation in POM was considerably related to SMBC and it had positive correlation with SMBC, in AESR 6.3 (r=0.53) and

significant correlation in AESR 10.2 (r=0.92**). POM and SMBC are considered as biologically active fractions of SOM (soil organic matter) and they have been found to predict the direction and rate of change of soil quality earlier and better than other indicators (Rao and Manna, 2005).

4.5.6 Culturable microbial population

Microorganisms are responsible for many transformations in soils related to plant nutrition and health. They are responsible for beneficial processes such as organic matter decomposition, humus formation and altered nutrient solubility making otherwise unavailable nutrients available to plant. They also play major role in formation of good soil structure. Scientific understanding of microbial biogeography is particularly weak, even though the diversity and composition of soil microbial communities is thought to have a direct influence on a wide range of ecosystem processes (Schimel, 1995; Hansel et al., 2008).

Although a few reports are available on soil microbial activities (Rao and Venkateswarlu 1983; Goyal et al., 1992; Manna and Singh 2001; Selvi et al., 2004; Vineela et al., 2008; Sharma et al., 2009), information on the impacts of different bioclimates, cropping systems, land use systems, and management practices on culturable microbial population is still lacking. Hence in our present study, we have studied the effects of edaphic and management practices on the microbial population in the soil.

The status of culturable microbial population (bacteria, fungi and actinomycetes) in soils of both the AESRs is presented in table 4.6 and fig. 4.10. In AESR 6.3, among the six soils, the bacterial population was the highest in P6 (6.5 X 10^5 cfu g^{-1}) followed by P3 (6.3 X10^5 cfu g^{-1}) and the lowest was recorded in P4 (5.6 X10^5 cfu g^{-1}). The fungal population was highest in P6 (6.2 X 10^5 cfu g^{-1}) followed by P3 (6.1 X10^5 cfu g^{-1}) and the lowest in P4 (5.4 X10^5 cfu g^{-1}). The actinomycetes

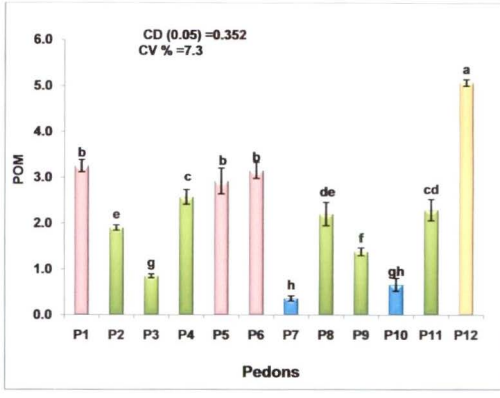


Fig. 4.9 Particulate organic matter (POM)

(Error bars (±SD) with the same letter are not significantly different (α 0.05))

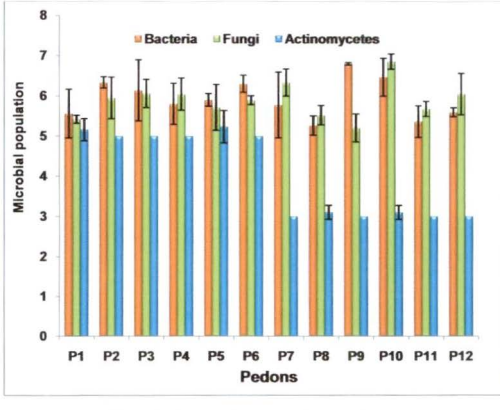


Fig. 4.10 Culturable microbial population

populations were found to be the highest in P6 (5.4 $X10^5$ cfu g^{-1}) followed by P3 (5.3 $X10^5$ cfu g^{-1}) and lowest in P4 (4.9 $X10^5$ cfu g^{-1}).

In AESR 10.2, among the six soils, the bacterial population was the highest in P10 (6.8 $X10^5$ cfu g^{-1}) followed by P9 (6.5 $X10^5$ cfu g^{-1}) and the lowest in P8 (5.3 $X10^5$ cfu g^{-1}). The fungal population was the highest in P10 (6.9 $X10^5$ cfu g^{-1}) followed by P12 (6.0 $X10^5$ cfu g^{-1}) and the lowest in P9 (5.2 $X10^5$ cfu g^{-1}). Actinomycetes populations were found to be the highest in P10 (3.9$X10^5$ cfu g^{-1}) followed by P9 (3.5$X10^5$ cfu g^{-1}) and lowest in P11 (3.0 $X10^5$ cfu g^{-1}).

The low microbial population in soils of both the AESRs may be due to their relatively high pH. The soils were moderately alkaline to strongly alkaline and higher alkalinity would have affected the microbial population in the soil. Similar results were observed by Baker et al. (2009); Lauber et al. (2009) and Kuramae et al. (2010) who observerd that the soil pH is the main factor to affect microbial population and structure. Soil pH has been reported to be the best predictor of bacterial community composition across the landscape whereas fungal community composition was most closely associated with changes in soil nutrient as observed by Lauber et al. (2008).

Variations in microbial populations among different pedons despite similar climatic conditions may be due to differences in their physical and chemical characteristics. The findings are in conformity with the findings of Buyer et al. (1999); Lawlor et al. (2000); Girvan et al. (2003); Bronick and Lal (2005) and Kuramae et al. (2012). They reported that the variations in microbial populations among the soils are mainly attributed to the differences in their physical and chemical properties. Soil type has been reported as the principal factor determining soil microbial communities and their structure. Schutter et al. (2001) also reported that although seasonal and field-dependent factors are major determinants of microbial community structure, shifts can occur as soil physical and chemical properties change in response to alternative practices.

The time of sampling also affected microbial population as there was insufficient moisture content in field at the sampling stage. In general, soil moisture is reported to influence the microbial activity in soils (Schimel et al., 1999), variations in the frequencies and intensity of precipitation influence the spatiotemporal extent of fungal and bacterial activities (Collins et al., 2008). Soil microbial functional diversity was found to decrease with increasing latitude and was positively correlated with measures of atmospheric temperature and higher acidity (Staddon et al., 1998). Low organic matter content and poor moisture availability of soils were the major factors limiting optimum microbial activity (Rao and Venkateswarlu, 1983). Various soil management and their cultural practices were shown to influence soil microbial populations and their activities based on Cluster and discriminate analysis (DA) reported that agricultural management, especially historic P fertilization, altered soil nutrient availability and consequently modified the microbial community composition and function (Lawlor et al., 2000; Wu et al., 2008; Meriles et al., 2009; Kuramae et al., 2012;. Ye and Wright, 2010). Jesus et al. (2009) reported that the main differences in bacterial community structure were related to changes in the soil attributes (base saturation, and pH) that, in turn, were correlated to land use.

4.5.7 Microbial diversity

Microbial diversity is a general term used to include genetic diversity, that is, the amount and distribution of genetic information, within microbial species; diversity of bacterial and fungal species in microbial communities; and ecological diversity, that is, variation in community structure, complexity of interactions, number of tropic levels, and number of guilds.

Scientific understanding of microbial biogeography is particularly weak, even though the diversity and composition of soil microbial communities is thought to have a direct influence on a wide range of ecosystem processes (Schimel, 1995; Hansel et al., 2008). Much of the recent work in soil microbial ecology has focused on categorization of

the diversity of soil bacteria and documenting how soil bacterial communities are affected by specific environmental changes or disturbances (Buckley and Schmidt, 2001). In general, different cropping systems and crop rotations improve soil quality indicators and crop yields in humid temperate regions, less information is, however, available under arid tropical and sub-tropical conditions with respect to soil microbial population. Due to only a few studies that have been conducted on soil microbial activities in these regions (Rao and Venkateswarlu, 1983; Goyal et al., 1992; Manna and Singh, 2001; Selvi et al., 2004; Vineela et al., 2008; Sharma et al., 2009).

Microbial diversity indices such as Shannon-Weaver Index (*H'*), Shannon Evenness Index (E1), Simpson's Evenness Index (E2) and Simpson's Index (*D*) were determined on the basis of microbial population as presented in table 4.6 and fig. 4.11. In our study, we considered microbial diversity simply to include the number of different fungal and bacterial species (richness) and their relative abundance (evenness) in soil microflora. Equations used to calculate species richness and evenness and diversity indices, which combine both richness and evenness, have been discussed by Kennedy and Smith (1995).

In AESR 6.3, among the six soils, Shannon-Weaver Index (*H'*) was the highest in P5 (2.64) whereas it was the lowest in P6 (2.03). The highest Shannon Evenness (E1) was recorded in P5 (0.88) and it was the lowest in P6 (0.37). Simpson's Evenness (E2) was the highest in P5 (0.57) whereas it was the lowest in P6 (0.41) and Simpson's Index (*D*) was recorded highest in P6 (0.55) whereas lowest in P5 (0.37). It is concluded from the above results that P5 was richest with respect to number of different fungal and bacterial species and it was also found to be high in their relative abundance (evenness).

Table 4.6 Culturable microbial population and microbial diversity indices of soils

Pedon No.	Culturable microbial population (10^5 cfu g^{-1})			Microbial diversity indices			
	Bacteria	Fungi	Actinomycetes	Shannon-Weaver Index (H')	Shannon Evenness Index (E1)	Simpson's Index of Diversity (D)	Simpson's Evenness Index (E2)
AESR 6.3							
P1	5.8	6.0	5.1	2.54	0.85	0.39	0.55
P2	6.1	5.9	5.0	2.17	0.71	0.48	0.47
P3	6.3	6.1	5.3	2.08	0.67	0.52	0.44
P4	5.6	5.4	4.9	2.27	0.75	0.46	0.50
P5	5.9	5.7	5.2	2.64	0.88	0.37	0.57
P6	6.5	6.2	5.4	2.03	0.64	0.55	0.41
AESR 10.2							
P7	5.8	6.3	3.2	2.16	0.70	0.48	0.47
P8	5.3	5.5	3.3	2.75	0.92	0.29	0.65
P9	6.5	5.2	3.5	1.24	0.20	0.91	0.08
P10	6.8	6.9	3.9	2.03	0.64	0.53	0.43
P11	5.4	5.7	3.0	2.55	0.85	0.36	0.58
P12	5.6	6.0	3.3	1.95	0.61	0.60	0.36

In AESR 10.2, among the six soils, highest Shannon-Weaver Index (H') was recorded in P8 (2.75) whereas lowest in P9 (1.24); Shannon Evenness (E1) was the highest in P8 (0.92) and the lowest in P9 (0.20). Simpson's Evenness (E2) was the highest in P8 (0.65) whereas it was the lowest in P9 (0.08) and Simpson's Index (*D*) was the highest in P9 (0.91) and the lowest in P8 (0.29). It is concluded that P8 was rich in the number of different fungal and bacterial species. It was also found to be the highest in their relative abundance (evenness).

The diversity indices were found to be low in AESR 6.3 which might be due to the salinity and sodicity problems in soils. Similar results were observed by Rietz and Haynes (2003) who concluded that salinity and sodicity not only influence the chemical and physical characteristics of soils but also greatly affect soil microbial and biochemical properties. In general, soil moisture is reported to influence the microbial activity in soils (Schimel et al., 1999), variations in the frequencies and intensity of precipitation influence the spatiotemporal extent of fungal and bacterial activities (Collins et al., 2008).

Studies on bacterial communities in soils and sediments (Zhou et al., 2002 and Carson et al., 2010) and in microcosms (Treves et al., 2003), indicate that hydraulically-induced spatial isolation in drier soils leads to higher diversity (richness and evenness) relative to wetter, more hydraulically connected soil or sediment environments. Increased fragmentation of the water phase within three-dimensional habitable pore space in soil results in a larger number of hydrated microhabitats available for colonisation. This, in turn, increases the potential for multiple species to coexist in close proximity without directly competing for resources.

The maximum diversity was observed in the surface soils. The legume-based and cereal-based cropping systems showed higher diversity indices whereas lower diversity indices were observed in

cotton based cropping system in different agroecological subregions of the black soil region in India (Velmourougane et al., 2012).

Based on the preceding discussion on various properties of the soils in the selected two AESRs, an attempt is made to compare them (the soil properties) across the AESRs. Morphologically, not much variations were found in soils of both the AESRs as they belong to the same parent material (basalt). In case of physical properties, sHC was found to be lower in AESR 6.3 as compared to AESR 10.2, which indicate very poor internal drainage; BD was higher in AESR 6.3 as compared to AESR 10.2. In case of chemical properties, $CaCO_3$, exchangeable Na, ESP and SAR were higher in AESR 6.3 as compared to those in AESR 10.2 which could be due to semi-arid climatic conditions; exchangeable Na, ESP and SAR in soils of AESR 6.3 were also observed to increase with depth. Exchangeable Ca and CEC were found to be higher in AESR 10.2 as compared to AESR 6.3. In case of biological properties, SMBC and DHA were found to be higher in AESR 10.2 as compared to AESR 6.3.

4.6 Seed cotton yield

Under identical set of management, crop yield can be an important indicator of soil quality, because it serves as a plant bioassay of the interacting soil characteristics. Otherwise also, the ultimate outcome of good soil quality is yield or economic produce.

The three year (normal year, worst year and best year) yield data were collected from farmers' fields and average yield (q /ha) was determined (Table 4.7 and Fig. 4.12). In AESR 6.3, pedon 3 had the highest average yield of 29 q /ha and the lowest average yield of 13.5 q/ha was recorded in pedon 2. In AESR 10.2, pedon 12 had the highest average yield of 35 q/ha and the lowest yield was observed in pedon 11 with an average yield of 12 q /ha.

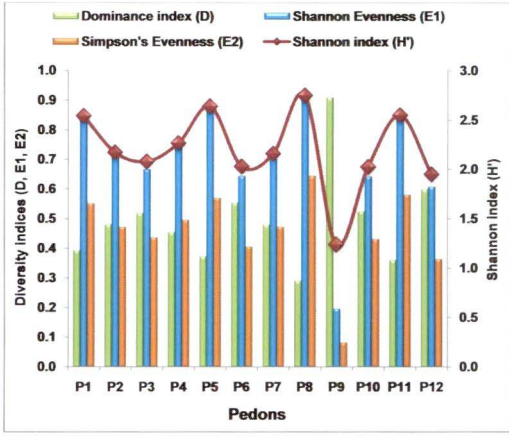


Fig. 4.11 Microbial diversity indices

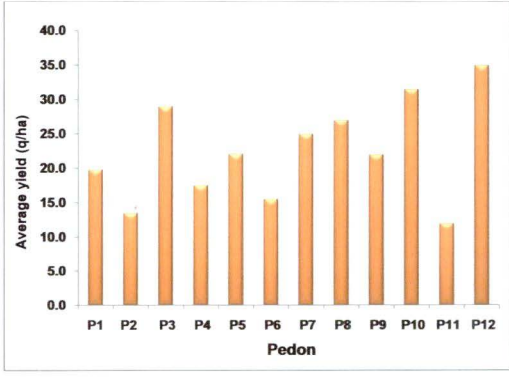


Fig 4.12 Average yield (q/ha) of seed cotton

Table No. 4.7 Average yield (q/ha) of seed cotton

Pedon No.	Normal year	Worst year	Best year	Average yield (q /ha)
AESR 6.3				
P1	19.9	17.1	22.4	19.8
P2	14.4	10.5	15.6	13.5
P3	28.0	25.9	33.1	29.0
P4	17.1	12.5	23.0	17.5
P5	19.7	18.7	27.9	22.1
P6	16.2	13.2	17.3	15.6
AESR 10.2				
P7	25.2	22	27.8	25.0
P8	26.3	26	28.7	27.0
P9	21.9	20.4	23.7	22.0
P10	30.2	28.4	35.9	31.5
P11	12.1	9.7	14.2	12.0
P12	36.8	29.8	38.4	35.0

Under rainfed conditions, the yield of deep-rooted crops in Vertisols depends primarily on the amount of rain stored at depth in the soil profile, and the extent to which this soil water is released during crop growth. Cotton yield was influenced by deep and very deep soils viz., P3 (150+ cm), P5 (152+ cm), P10 (108 cm) and P12 (150+ cm). Yadav et al. (1999) also observed that depth of soil affects the yield of cotton in Vidarbha region, Maharashtra. Higher yield was obtained in AESR 10.2 (sub-humid region) as compared to that in AESR 6.3 (semi-arid region). Pal et al. (2009) also observed higher yield in deep cracking clay soils (Vertisols) of Peninsular India under farmer's similar soil management and also under similar soil moisture and temperature regimes. They reported higher yield of cotton in soils of Nagpur (1.0 to 1.8 t/ha) than in Akola (0.6 to 1.0 t/ha).

4.7 Soil quality (SQ) assessment using different methods

Selection of indicators: In total, 8 physical factors (depth, sand, silt, clay, field capacity, permanent wilting point, AWC and sHC); 21 chemical factors (pH, EC, OC, $CaCO_3$, exchangeable cations (Ca, Mg, Na and K), CEC, percent BS, SAR, ESP, EMP, available N, P and K and micronutrients viz., Fe, Mn, Zn and Cu) and 7 biological factors (microbial count, SMBC, soil respiration, DHA, nitrogen mineralization, POM and microbial diversity indices. Microbial diversity indices such as Shannon-Weaver Index, Shannon Evenness Index, Simpson's Evenness Index and Simpson's Index were computed and evaluated to derive minimum dataset in the study area. For physical and chemical indicators, the weighted means of all the pedons were calculated (Table 4.8) and the final value of weighted means (0-150 cm) was taken for each pedon. The biological properties of the studied soils on the other hand were determined for soil depth 0-30 cm.

Use of minimum datasets (MDS): The MDS in the present study has been developed using different approaches, one using expert knowledge and the other through use of correlation and Principal Component Analysis (PCA).

Table 4.8 Weighted means of all properties of soils

Pedon No.	Depth (cm)	Particle size distribution (%)			BD (Mg/m^3)	Water retension (%)		AWC (%)	sHc (mm/hr)	pH	EC (dSm^{-1})	OC (%)	$CaCo_3$ (%)
		Sand	Silt	Clay		at 1/3 bar	at 15 bar						
P1	150	1.58	39.08	59.34	1.72	34.48	22.43	12.05	1.34	8.7	0.34	0.35	18.14
P2	43	22.46	37.71	39.81	1.61	27.60	14.45	13.16	1.69	8.2	0.26	0.41	5.04
P3	150	0.97	38.19	60.84	1.67	35.79	20.70	15.09	3.23	8.5	0.17	0.31	15.77
P4	143	0.52	32.02	67.45	1.64	43.25	27.93	15.32	1.82	8.6	0.52	0.44	8.97
P5	120	0.76	33.27	65.98	1.57	40.55	26.81	13.74	2.40	8.4	0.23	0.45	10.11
P6	91	7.55	24.81	67.64	1.62	43.39	29.19	14.20	0.67	8.1	0.20	0.52	6.16
P7	150	8.79	34.81	56.40	1.36	30.60	17.45	13.15	1.79	8.7	0.21	0.44	10.23
P8	152	3.90	35.72	60.37	1.47	32.12	21.91	10.21	1.54	8.6	0.22	0.31	10.66
P9	35	33.16	30.73	36.11	1.42	26.07	16.98	9.09	3.20	8.3	0.38	0.42	5.09
P10	108	2.21	32.98	64.81	1.57	39.46	27.84	11.62	1.80	8.5	0.18	0.36	7.36
P11	15	13.44	22.13	64.44	1.47	39.51	28.33	11.18	2.03	8.3	0.53	0.62	12.15
P12	150	13.37	39.92	66.71	1.34	41.66	29.10	12.56	2.85	8.6	0.18	0.48	8.55

Contd.....

Pedon No.	Exchangeable cations				CEC	Sum of Bases	BS %	SAR	ESP	EMP	Avail N	Avail P	Avail K	Fe	Mn	Zn	Cu
	Ca	Mg	Na	K													
	..... (cmol (p^+) kg^{-1})											(g/kg)			(mg/kg)		
P1	19.9	20.0	1.7	0.5	43.1	42.0	96.5	3.3	4.6	48.1	7.84	1.85	79.97	5.8	3.8	0.3	2.0
P2	16.7	12.3	0.7	0.6	27.1	30.3	112.2	0.8	2.5	46.4	7.28	8.19	87.41	7.2	6.1	0.4	2.3
P3	34.9	13.9	0.7	0.8	48.9	50.2	102.8	0.6	1.4	28.5	10.08	2.53	94.84	5.0	3.2	0.2	1.5
P4	26.3	20.1	3.8	0.6	46.9	50.8	109.0	4.8	7.7	43.4	7.28	1.55	84.93	7.0	3.3	0.2	1.8
P5	38.7	17.5	1.0	0.8	52.6	57.9	110.4	1.0	1.9	33.1	7.84	5.00	107.24	6.9	5.4	0.2	1.9
P6	48.0	17.1	0.7	0.7	58.8	61.2	103.9	0.5	1.2	20.1	10.64	8.75	102.28	6.7	7.5	0.3	3.1
P7	32.4	17.1	1.0	0.5	51.3	51.0	99.5	1.0	1.9	33.2	13.44	13.20	127.07	6.2	8.1	0.6	2.6
P8	31.3	22.5	0.6	0.7	53.1	55.2	103.9	0.7	1.1	41.9	12.32	11.23	112.20	4.7	6.3	0.2	1.4
P9	22.4	11.6	0.8	1.2	33.6	36.0	107.2	0.8	2.5	34.5	12.32	13.08	87.41	7.5	6.5	0.6	4.6
P10	46.5	11.4	0.4	0.5	54.5	58.7	107.9	0.3	0.8	20.9	12.88	2.78	57.66	5.7	8.4	0.2	1.3
P11	53.5	8.8	0.7	0.9	59.2	63.9	108.0	0.4	1.2	14.9	15.12	6.20	87.41	9.0	14.2	0.7	3.8
P12	48.3	15.8	0.7	0.4	57.9	65.1	112.5	0.6	1.2	27.6	14	14.10	84.93	7.3	10.5	0.4	3.2

4.7.1 Development of MDS using expert knowledge

Selection of attributes: Selection of the attributes comprising physical, chemical and biological properties of soils that best represent soil functions is made using expert knowledge (Sys, 1985; NBSS & LUP, 1994; Chatterji, 2000; Chatterji et al., 2002; Kadu et al., 2003; and Naidu et al., 2006 Venugopalan et al., 2009). For minimum datasets, 5 soil attributes comprising 3 physical (depth, clay and sHC), 1 chemical (ESP) and 1 biological (SMBC) properties of soils were selected. Depth, clay and hydraulic conductivity offer reflection on the suitability of cotton as it has deep root system. ESP influences mainly water retention which affects physical and chemical properties of the soils. SMBC represents the fraction of soil responsible for energy and nutrient cycling and regulation of organic matter transformation. All these factors have, therefore, been used to reflect the various aspects of soil quality in relation to plant growth.

The MDS of attributes so developed through expert knowledge were used for assessing SQ through two approaches namely, one based on computation of Relative Soil Quality Index (RSQI) and the other based on computation of Composite Soil Index (CSI) using fuzzy modelling-based method.

A. SQ assessment based on RSQI – A conventional approach

In this method, 5 soil attributes comprising physical (depth, clay and sHC), chemical (ESP) and biological (SMBC) properties of soils were used.

Weight of attributes: The weight for each attribute (Table 4.9) was assigned depending upon available knowledge about its relative role in influencing crop yield and also on the basis of existing soil conditions, cropping pattern and agro-climatic conditions of the study area as also done by Davidson et al. (1994) and Kundu et al. (2012). As depth is known to contribute more to influence cotton yield, it was, therefore, assigned the highest weight of 40, saturated hydraulic conductivity was next important property so it had a weight of 30,

whereas clay, ESP and SMBC had a weight of 10 each. The sum of all the weights was normalized to 100 %.

Table No. 4.9 Soil quality indicators, their weights and classes

Soil quality indicator	weig hts	class I with score 4	class II with score 3	class III with score 2	class IV with score 1
Depth (cm)	40	> 100	100-60	60-30	<30
sHC (mm/hr)	30	>5.5	5.5-2.5	2.5-1.5	<1.5
Clay (%)	10	35-50	<35	50-60	>60
SMBC (µg/g)	10	>90	90-65	65-45	<45
ESP	10	>1.5	1.5-2.5	2.5-4.5	>4.5

Score of attributes: The status of each attribute was categorized according to class along with its score (Table 4.9) and the categorization of score was done on the basis of available literature (Sys, 1985 and Naidu et al., 2006). Lower the class means higher the score obtained by each attribute. The range of score varied from 1 to 4, so the theoretical range of SQI was 100 to 400 i.e. the minimum value of SQI was 100 and maximum value of SQI 400 (Wang and Gong, 1998). In order to judge the SQI value of any site against the theoretical maximum value of SQI, the concept of relative soil quality index (RSQI) enumerated by Karlen and Stott (1994) was used.

The SQI and RSQI values of soils of both the AESRs were calculated (Table 4.10). The highest RSQI in AESR 6.3 was obtained for pedon 3 (72.5%) whereas the lowest was found for pedon 2 (52.5 %). On the other hand, in case of soils of AESR 10.2, the highest RSQI was obtained for pedon 12 (87.5 %) and the lowest RSQI for pedon 11 (47.5 %).

Table 4.10 Relative soil quality index (RSQI) of different pedons

Pedon No.	SQI	RSQI	Pedon No.	SQI	RSQI
AESR 6.3			AESR 10.2		
P1	270	67.50	**P7**	280	70.0
P2	210	52.50	**P8**	290	72.5
P3	290	72.50	**P9**	260	65.0
P4	230	57.50	**P10**	280	70.0
P5	280	70.00	**P11**	190	47.5
P6	240	60.00	**P12**	350	87.5

The results indicate that the RSQI was positively correlated with average yield. The linear regression lines were also drawn using RSQI values (x) with average yield (y) and their mathematical expressions were $y = 0.634 x - 20.62$ ($R^2 = 0.81$) for the soils of AESR 6.3 and $y = 0.58 x - 15.0$ ($R^2 = 0.89^{**}$ i.e. significant at 5% level) for the soils of AESR 10.2 (Fig. 4.13 and Fig. 4.14).

Based on RSQI values, the soils of both the AESRs were classified into three categories. The soils with a RSQI value less than 50% were rated as poor in quality. The soils having RSQI value ranging from 50-70% were rated as medium in quality and the soils having RSQI value more than 70% were rated as good in quality.

In AESR 6.3, pedons 1, 2, 4 and 6 were medium in soil quality whereas pedons 3 and 5 were good in soil quality. In AESR 10.2, pedons 7, 8, 10 and 12 were good in soil quality; pedon 9 was medium in soil quality and pedon 11 was poor in soil quality (Table 4.11).

Table 4.11 Grouping of soils into different categories based on RSQI

Pedon No.	RSQI	Quality rating	Pedon No.	RSQI	Quality rating
AESR 6.3			**AESR 10.2**		
P1	67.5	Medium	**P7**	70.0	Good
P2	52.5	Medium	**P8**	72.5	Good
P3	72.5	Good	**P9**	65.0	Medium
P4	57.5	Medium	**P10**	70.0	Good
P5	70.0	Good	**P11**	47.5	Poor
P6	60.0	Medium	**P12**	87.5	Good

It is observed from above discussion that the soils of AESR 10.2 had highest correlation of RSQI with average yield (R^2=0.90** i.e. significant at 5% level) as compared to those of AESR 6.3 (R^2= 0.81). The correlation of RSQI with average cotton yield was found to be significant in AESR 10.2 only but not in AESR 6.3 which might be due to semi-arid climatic condition, low sHC and high ESP. Similar results were also reported by Kadu et al. (2003) and they indicated that among the soil parameters, ESP and sHC were the yield influencing factors in Vertisols for deep rooted crops in semi-arid parts of central India. Similar results were observed by Pal et al. (2009) for Vertisols (cracking clay soils) in a climosequence of Peninsular India.

A similar method was used by Kundu et al. (2012) in studying the soil quality of AESR 10.1 who calculated the relative soil quality index based on 15 soil attributes which were known to exert significant influence on the productivity of wheat and chickpea in winter season

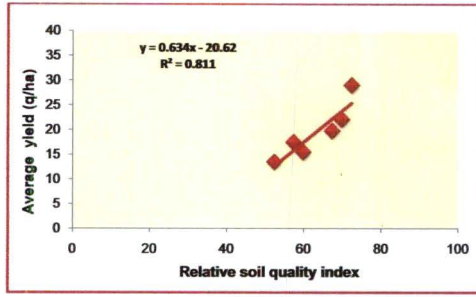


Fig. 4.13 Relative soil quality index (RSQI) of AESR 6.3

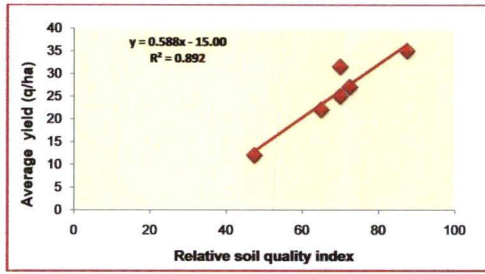


Fig. 4.14 Relative soil quality index (RSQI) of AESR 10.2

and soybean and rice in rainy season. The soils with RSQI values less than 50 % were rated as poor, 50-70 % as medium category and more than 70% as good quality soils. They observed that about 4, 78 and 18 percent soil samples of Sehore district and 16, 78 and 66 percent soil samples of Vidisha district, Madhya Pradesh belonged to poor, medium and good quality categories, respectively. They concluded that the proposed methodology appears to be very simple and can be easily adopted by soil testing laboratories.

B. SQ assessment using mathematical approach (fuzzy modelling-based method)

The soil parameters viz., depth, sHc, clay and ESP were selected as indicators for cotton. Biological properties are not considered as SQ indicators in this method because fuzzy modelling-based mathematical approach is the process of land evaluation and considers only physical and chemical properties of soils. Depth is an important criterion for cotton which has deep rooting system. sHC is an important parameter of soil which governs movement of water in the soils. Soils with high sHC allow movement of water to the deeper layers which can be utilized by the cotton roots. Clayey soils (vertic properties) are preferable as it can hold more water. High sodium percentage leads to structural decline e.g. dispersion of soil aggregates into individual soil particles leading to reduced water availability, low sHC, low permeability and reduced crop yield as a result of reduced availability of other nutrients.

Computation of membership functions: The ranks and statistics of standard indices, the dispersion indices and weightages (computed through ranking approach) for cotton are presented in table 4.12. The same were required for developing membership functions.

Table 4.12 Ranks, values of different indices for selected parameters (MDS) and weightages for computing membership functions

Selected Parameters	Rank	Standard index (X_i)	Dispersion Index (a_i)	Weightage (W_i)
Depth (cm)	4	> 90	0.0004	0.4
sHC (mm hr^{-1})	3	> 12.5	0.0070	0.3
Clay (%)	2	$\leq$ 27.5	0.0006	0.2
ESP	1	< 5	0.0565	0.1

Standard indices (Xi) for the MDS components for cotton were finalised on the basis of their point/range values in the highly suitable class (Naidu et al., 2006) and knowledge of experts on the soils in relation to the crop (NBSS & LUP, 1994). The standard indices considered for depth were >90 cm, for sHC > 12.5 mm hr^{-1}, for clay $\leq$ 27.5 % and for ESP < 5.

A value of dispersion index (a_i) 0.0004 developed for depth (Table 4.12), implies that the various soil units have their depth belongingness to the ideal value scattered within a band of 0.0004 measure. Similar interpretation of dispersion indices holds good for other properties as well. Ranking was assigned to each parameter based on the relative importance of that parameter to the cultivation of cotton crop and was based on local experts' knowledge (Chatterji, 2000; Chatterji et al., 2002; Kadu et al., 2003; Venugopalan et al., 2009) and available literature and the weightages were derived using the relationship in $eq^n(1)$ mentioned in the chapter on Materials and Methods. Depth, being the most important parameter for cotton, was assigned the highest rank of 4, sHC 3, clay 2 and ESP was assigned the lowest rank of 1. The weightages derived from the ranking were 0.4

for depth, 0.3 for sHC, 0.2 for clay and 0.1 for ESP with their total normalized to unity (1).

The membership functions of the relevant parameters in the given pedons for cotton are presented in table 4.13. The membership functions (or values) indicate the degree of suitability at a given location with respect to a given land characteristic. On a 0~1 scale, any parameter having a membership of 1 (highly suitable class) in any land unit suggests that the parameter has the complete belongingness to a particular class. The membership value of depth for pedon 1 is 1.0 which implies that the parameter has a belongingness of 100 percent to that class. Similarly, membership value of sHc for pedon 9 is 0.63, clay for pedon 2 is 0.99, ESP for pedon 4 is 0.70 which implies that the parameter has a belongingness of 63, 99 and 70 percent to that class respectively.

Table 4.13: Membership Functions (Ei) of MDS constituents

Pedon No.	Depth	sHc	Clay	ESP
AESR 6.3				
P1	1.00	0.51	0.69	1.00
P2	0.53	0.59	0.99	1.00
P3	1.00	0.57	0.63	1.00
P4	1.00	0.50	0.53	0.70
P5	1.00	0.55	0.57	1.00
P6	1.00	0.51	0.53	1.00
AESR 10.2				
P7	1.00	0.57	0.63	1.00
P8	1.00	0.58	0.57	1.00
P9	0.45	0.63	0.98	1.00
P10	1.00	0.59	0.54	1.00
P11	0.31	0.57	0.55	1.00
P12	1.00	0.60	0.62	1.00

The joint membership function (JMF) is a sum of the product of MF and weightage (Table 4.14). The composite soil index (CSI) of a SQ parameter is the average of the aggregated JMF values of the parameters for a particular pedon which conceptually and for all practical purposes holds the same implication as that by SQI.

Table 4.14 Joint membership functions (JMFs), composite soil indices (CSI) and land classes for cotton in fuzzy modelling

Pedon No.	Depth	sHc	Clay	ESP	CSI	Land Classes
AESR 6.3						
P1	0.40	0.15	0.14	0.10	79.02	II
P2	0.21	0.18	0.20	0.10	68.68	II
P3	0.40	0.17	0.13	0.10	79.63	II
P4	0.40	0.15	0.11	0.07	72.62	II
P5	0.40	0.16	0.11	0.10	77.93	II
P6	0.40	0.15	0.11	0.10	76.05	II
AESR 10.2						
P7	0.40	0.17	0.13	0.10	79.82	II
P8	0.40	0.17	0.11	0.10	78.88	II
P9	0.18	0.19	0.20	0.10	66.57	II
P10	0.40	0.18	0.11	0.10	78.69	II
P11	0.12	0.17	0.11	0.10	50.28	III
P12	0.40	0.18	0.12	0.10	80.39	I

The suitability classes for the crops were identified by placing the CSI values (of the land units) in a set of equally-spaced classes on

a 0-100 scale, with a 20 unit gradation. CSI lying between 100-80 comes under class I, CSI lying between 80-60 comes under class II, CSI lying between 60-40 comes under class III, CSI between 40-20 comes under class IV and class V has CSI value ranging from 20-0.

In AESR 6.3, all the pedons were classified under class II (P1, P2, P3, P4, P5 and P6). The composite soil index (CSI) was found to be the highest in P3 (79.63) whereas the lowest CSI was found in P2 (68.68). In AESR 10.2, pedon 12 was classified under class I; pedons 7, 8, 9 and 10 were classified under class II and pedon 11 was classified under class III. The highest CSI was observed in P12 (80.39) whereas the lowest CSI was observed in P11 (50.28).

The linear regression lines were also drawn (Fig 4.15 and Fig. 4.16) using a CSI value (x) and the average yield (y) and their mathematical expressions were $y = 1.007x - 56.65$ for AESR 6.3 and the correlation between CSI and average yield was $R^2 = 0.59$. However, when P6 was considered as an outlier, their mathematical expressions were $y = 1.031x - 57.54$ and R^2 value improved from 0.59 to 0.72. For AESR 10.2, they were $y = 0.606 x - 18.49$ and the correlation between CSI and average yield was $R^2 = 0.822^{**}$. It was observed from above discussion that CSIs of AESR 10.2 had good correlation with average yield as compared to those of AESR 6.3.

Pedon 6 (AESR 6.3) having high residual value is considered as an outlier while developing the relationship between CSI and average yield. In case of the outlier, inspite of CSI being high, the crop performs poorly. Hence, it might be interpreted from the results that proper management is lacking in this outlier soil profile to deliver optimum yield and hence site specific management must be improved in this site.

The use of the fuzzy technique is helpful for land suitability evaluation, especially in applications in which subtle differences in soil quality are of a major interest.

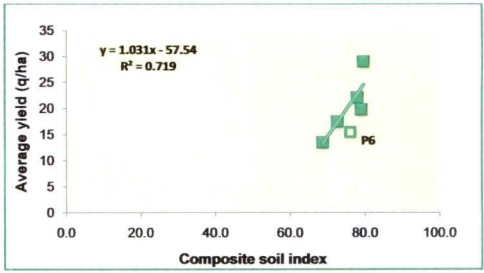


Fig 4.15 Composite soil index (CSI) of AESR 6.3

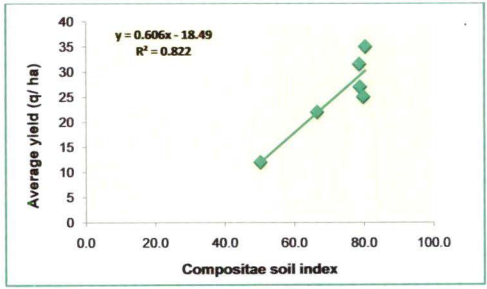


Fig 4.16 Composite soil index (CSI) of AESR 10.2

4.7.2 Development of MDS using Principal Component Analysis (PCA)

Identification of minimum datasets (MDS): Pearson correlation matrix between average yield of cotton crop and soil properties was developed. Those parameters which are mutually exclusive and locally relevant having significant correlation (two tailed test, $p<0.05$) with yield were considered for further analysis. The correlation matrix revealed higher correlation of crop yield with 13 soil properties viz., depth, clay, sHC, EC, OC, exchangeable Mg, exchangeable K, CEC, BS %, SMBC, DHA, nitrogen mineralization and Shannon-Weaver index which meet the abovementioned criteria. Hence, these 13 properties were considered for further analysis using Principal Component Analysis (PCA).

Principal Component Analysis (PCA): Above 13 parameters were retained for PCA using SPSS software version 11.5. Principal components (PC) for a data set are defined as linear combinations of variables to reduce number of variables so that they account for maximum variance explanation within the set by describing vectors of closet fit to the n observation in p-dimensional space, subject to being orthogonal to one another. The principal components receiving high eigen values and variables with high factor loading were assumed as the variables that best represent system attributes (Brejda et al., 2000). Therefore, only the PCs with eigen values 0.9 or greater, which explained at least 7% of the variation in the data were examined.

PCA analysis in scree plot (Fig. 4.17) and table 4.15 show that five PCs had eigen values > 0.9 and were able to explain 86.25 % variation. Within each principal component, only highly weighted factor loading (indicated in bold numbers in table 4.16) were retained for the MDS.

Table 4.15 Results of principal component analysis (PCA) of soil quality indicators of statistically significant variable ($p<0.05$)

Component	PC1	PC2	PC3	PC4	PC5
Eigen Value	4.33	3.18	1.74	1.06	0.91
% of Variance	33.28	24.46	13.36	8.17	6.98
Cumulative %	33.28	57.75	71.11	79.27	86.25
Weightage	0.386	0.283	0.155	0.095	0.081

Table 4.16 Factor loading/ eigen vectors of PCA

Variable	PC1	PC2	PC3	PC4	PC5
Depth	**0.878987**	-0.35564	-0.01994	-0.0155	0.062576
Clay	**0.711854**	0.567662	0.103374	0.007309	0.027713
sHC	-0.53181	-0.32173	**0.702422**	0.161881	-0.06867
EC	-0.41581	0.46316	-0.624	0.19714	0.138765
OC	-0.31552	**0.807918**	6.32E-05	-0.39382	0.116352
Exchangeable Mg	**0.790957**	-0.23847	-0.37366	-0.11379	0.033573
Exchangeable K	-0.64794	0.084332	-0.14826	-0.07217	-0.42424
CEC	0.567084	0.658554	0.393832	-0.11538	-0.10007
BS %	-0.44904	0.093418	0.347232	-0.26157	**0.718351**
SMBC	-0.09012	**0.877297**	-0.08063	-0.23386	-0.23788
DHA	-0.16068	0.585988	0.333603	**0.701809**	-0.01839
Shannon-Weaver index	0.580204	0.368325	-0.21982	0.416448	0.273058
Nitrogen Mineralisation	**0.743448**	0.07556	0.489611	-0.14323	-0.16381

* factor loading scores in bold are considered highly weighted

PCA –based SQ assessment

After determining the MDS variables, each of them was scored on the basis of performance of soil function, considering soil type and variation of values within pedons and given on the basis of available literature (Sys, 1985 and Naidu et al., 2006) as shown in table 4.17. Each variable was transformed or standardized to a value between 0.1 (least favorable soil function) scoring function and 1 (most favourable soil function) scoring function (Andrews et al., 2002[b]). Highly weighted variables under PC1 include depth, clay, exchangeable Mg and nitrogen mineralization. PC2 includes OC and SMBC, PC3 includes sHc, PC4 includes DHA and PC5 includes BS %.

Table 4.17: Scoring chart for selected soil variables based on the soil type and the variation of values within the pedons

Score	Depth (cm)	OC (%)	Ex Mg (cmol (p^+) kg^{-1})	BS %	sHc (mm/hr)	Clay (%)	SMBC (µg/g)	DHA (µg TPF g^{-1})	N Min (kg/ha)
0.1-0.25	<30	0.2-0.4	>19	-	<1.5	-	-	-	-
0.25-0.5	30-60	0.4-0.6	19-16	<60	2-1.5	-	-	<1.5	-
0.5-0.75	60-80	0.6-0.8	16-13	80-60	2.5-2	< 65	<45	3.5-1.5	<15
0.75-1	80-100	0.8-1	13-10	100-80	3-2.5	>35	65-45	5.5-3.5	35-15
1	>100	>1	<10	>100	>3	35-65	>65	>5.5	>35

Soil Quality Index Interpretation: The MDS variables for each observation were weighted by using the PCA results. Each PC explained a certain amount (%) of the variation in the total data set. This percentage, divided by the total percentage of variation explained by all PCs with eigenvectors greater than 0.9 provided the weighted factor for variables chosen under a given PC. The SQI was calculated by using weighting factors for each scored MDS, the final formula $SQI = \sum Wi\,Si$,

Where W_i is the PC weighting of i^{th} factor and S_i is the score of i^{th} indicator. Here, the assumption was that higher index scores mean better soil quality or greater performance of soil functions.

In our case, SQI equation turned out to be

SQI = [0.386 x S (depth) + 0.386 X S (clay) + 0.155X S (sHc) + 0.283 X S (OC) + 0.386 X S (exchangeable Mg) + 0.081 X S (%BS) + 0.283 X S (SMBC) + 0.095 X S (DHA) + 0.386 X S (N mineralization)

In AESR 6.3, the highest SQI (Table 4.18) was obtained in P3 (1.63) and the lowest in P4 (1.33) whereas in case of AESR 10.2, the highest SQI was obtained in P12 (1.85) and the lowest in P9 (1.51). In both the AESRs, the relation between SQI and average yield (Fig. 4.18 and Fig. 4.19) was found to be linear and the mathematical expression was $y = 31.5x - 19.7$, $R^2 = 0.863^{**}$ for AESR 6.3. For AESR 10.2, it was $y = 24.41x - 10.35$ and the correlation between SQI and average yield was $R^2 = 0.19$. However, when P6 was considered as an outlier, their mathematical expressions were $y = 28.33x - 13.28$ and R^2 value improved from 0.19 to 0.79. Hence average yield can also be used as an alternative indicator of soil quality evaluation in terms of crop performance.

Table 4.18 Soil quality index (SQI) of different pedons developed by PCA in the two AESRs

Pedon No.	SQI	Pedon No.	SQI
AESR 6.3		AESR 10.2	
P1	1.53	P7	1.55
P2	1.36	P8	1.67
P3	1.63	P9	1.51
P4	1.33	P10	1.79
P5	1.61	P11	1.78
P6	1.37	P12	1.85

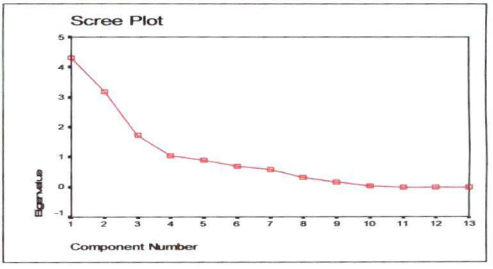


Fig 4.17 Scree plot obtained from PCA

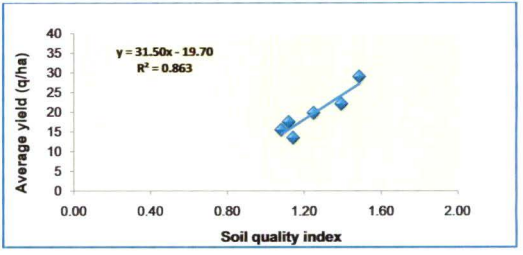


Fig. 4.18 Soil quality index (SQI) of AESR 6.3

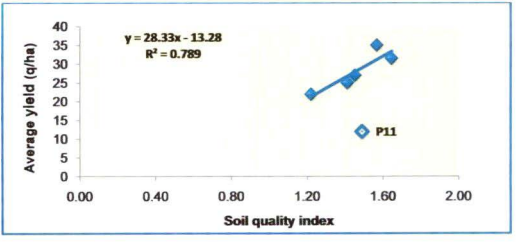


Fig. 4.19 Soil quality index (SQI) of AESR 10.2

Pedon 11 (AESR 10.2) having high residual value is considered as an outlier while developing the relationship between SQI and average yield. In case of the outlier, inspite of SQI being high, the crop performs poorly. Hence, it might be interpreted from the result that proper management is lacking in this outlier soil profile to deliver optimum yield and hence site specific management must be improved at this site.

- **Comparison of SQIs (as developed by three methods)**

SQIs developed by all the three methods in both the AESRs along with their ranks are presented in table 4.19.

Table 4.19 Comparison of SQIs developed by three methods

Pedon No.	Relative soil quality index (RSQI)	Fuzzy modelling-based method (CSI)	PCA-based method (SQI)
AESR 6.3			
P1	67.5 (3)	79.02 (2)	1.53 (3)
P2	52.5 (6)	68.68 (6)	1.36 (5)
P3	72.5(1)	79.63 (1)	1.63 (1)
P4	57.5 (5)	72.62 (5)	1.33 (6)
P5	70.0 (2)	77.93 (3)	1.61 (2)
P6	60.0 (4)	76.05 (4)	1.37 (4)
AESR 10.2			
P7	70.0 (3)	79.82 (2)	1.55 (5)
P8	72.5 (2)	78.88 (3)	1.67 (4)
P9	65.0 (4)	66.57 (5)	1.51 (6)
P10	70.0 (3)	78.69 (4)	1.79 (2)
P11	47.5 (5)	50.28 (6)	1.78 (3)
P12	87.5 (1)	80.39 (1)	1.85 (1)

* Value in the parenthesis indicates rank of pedon

The table indicates that in both the AESRs, the pedonwise results obtained with respect to SQ assessment from the three methods did not follow similar trend. In AESR 6.3, using RSQI method, the pedons in order of decreasing quality were P3>P5>P1>P6>P4>P2, those using fuzzy modelling-based method were in the order P3>P1>P5>P6>P4>P2 and the order obtained using PCA-based method was P3> P5 >P1>P6 >P2>P4. In AESR 10.2, the pedons were in the order P12>P8>P7>P10>P9>P11 using RSQI method, P12>P7> P8> P10>P9 >P11 using fuzzy modelling-based method and P12> P10 >P11 >P8 >P7 >P9 using PCA-based method.

It could be observed from the table that all the three methods of SQ assessment identified the same best quality pedon in each AESR namely, P3 in AESR 6.3 (with RSQI -72.5, CSI - 79.6 and SQI -1.63) and P12 in AESR 10.2 (with RSQI - 87.5, CSI - 80.3 and SQI - 1.85).

Correlation of AESR wise SQIs (as developed by the three methods) to average cotton yield indicates that in case of AESR 6.3, the correlation coefficient was higher in PCA-based method (R^2= 0.86**) than those obtained in conventional R^2=0.81 and fuzzy modelling-based method R^2= 0.59. However, when P6 was considered as an outlier, R^2 value improved from 0.59 to 0.72. The correlation of SQI with average yield in the conventional method was found to be higher in AESR 10.2 (R^2=0.90**) as compared to that in fuzzy modelling-based method (R^2= 0.82**). In case of PCA-based method, however, the correlation of SQIs with average yield was R^2= 0.19 but when P11 was considered as an outlier, R^2 improved to 0.79. The study indicates that the PCA-based method gives best results for AESR 6.3 and the conventional method gives best results for AESR 10.2 with respect to SQ assessment. The fuzzy modelling-based method, however, failed to provide value addition which could be attributed to non- consideration of biological parameter in the MDS and hence its inability to develop integrated soil quality index.

Based on the above discussion, it is observed that soils of all the pedons in AESR 6.3 were found to be low in saturated hydraulic conductivity, high in $CaCO_3$, exchangeable sodium and their sodium absorption ratio (SAR). It indicates that soils are sodic in nature which leads to imperfect drainage and low water retention capacity, an indicator of poor quality of the soil. Therefore, to overcome these constraints, there is need to apply amendment like gypsum for reclamation, grow dhaincha crop upto 50 % flowering stage and incorporate it into field which would reduce ESP over a period of time. Further, site specific nutrient management also needs to be adopted.

Cotton is a deep rooted crop but pedons 2 and 6 in AESR 6.3 and pedons 11 and 9 in AESR 10.2 were shallow in depth. Ideally these soils are not recommended for cotton cultivation (Naidu et al., 2006) and alternative shallow rooted, short duration crops may be adopted. In case, the farmers wish to continue with cotton, then they may be advised to adopt high density planting system (HDPS) using early, semi compact varieties recommended for this purpose in order to improve yield on these soils.

CHAPTER - V

SUMMARY AND CONCLUSIONS

The present investigation entitled, "Soil quality assessment in rainfed cotton growing environs of two agroecological regions of Vidarbha, Maharashtra" has been undertaken with the following objectives.

- To identify soil physical, chemical and biological indicators for rainfed cotton in selected agroecological regions.
- To develop an integrated soil quality index using conventional and mathematical approaches.
- To relate the soil quality index to crop productivity.

Twelve profiles from cotton growing areas of different agroecological subregions (AESR) of Vidarbha, Maharashtra, India, six each in AESR 6.3 (Akola district) and AESR 10.2 (Nagpur district) were selected, studied for their morphological, physical, chemical and biological properties and assessment for their quality.

Morphological properties

The soils, mostly clayey in texture, were well to moderately well drained and exhibited very dark grayish brown (10 YR 3/2) to dark grayish brown (10 YR 4/2) colour in both the AESRs. The surface horizons of all the pedons generally had sub-angular blocky structure and slightly hard to hard (dry) and friable to firm (moist) consistency. Slickensides were well developed in pedons 1, 3, 4, 5, 7, and 8. The pedons under study showed variation in soil depth viz., pedon 2, 9 and 11 were shallow; pedon 6 was moderately deep; pedons 4, 5, 8 and 10 were deep and pedons 1, 3, 7 and 12 were very deep.

Physical properties

All pedons in AESR 6.3 had high clay content (except pedon 2) and ranged from 53.6 to 68.1 percent which gradually increased with depth. In AESR 10.2, all pedons (except pedon 9) had high clay

content and ranged from 56.4 to 67.8 percent. The BD values of the pedons ranged from 1.48 to 1.72 Mg m^{-3} in AESR 6.3 whereas in AESR 10.2, it ranged from 1.36 to 1.62 Mg m^{-3}. In AESR 6.3, sHC of all the pedons ranged from 0.2 to 3.23 mm hr^{-1} except pedon 4 (0.1 to 1.8 mm hr^{-1}) and those in AESR 10.2, it ranged from 0.78 to 5.01 mm hr^{-1}. The available water capacity (AWC) ranged from 8.59 to 15.97 percent that gradually increased with clay content in both the AESRs.

Chemical properties

The pedons from both the AESRs were moderately to strongly alkaline in nature, with pH ranging from 8.0 to 8.8. The EC of the studied soils from both the AESRs ranged from 0.14 to 0.62 dSm^{-1}. The OC contents were low and ranged from 0.20 to 0.64 per cent in AESR 6.3 and from 0.15 to 0.77 per cent in AESR 10.2 and decreased with depth. The $CaCO_3$ contents in all the pedons in AESR 6.3 varied from 6.85 to 17.38 per cent and from 4.83 to 13.3 per cent in AESR 10.2. CEC of all the pedons ranged from 30.1 to 60.1 cmol (p^+) kg^{-1} in AESR 6.3 and from 46.5 to 65.9 cmol (p^+) kg^{-1} in AESR 10.2 and had significant positive correlation with clay in AESR 6.3 ($r=0.92^{**}$) as well as in AESR 10.2 ($r=0.94^{**}$). Exchangeable cations were present in the order, $Ca^{2+} > Mg^{2+} > Na^+ > K^+$ in the pedons of both the AESRs. AESR 6.3 had higher ESP (1.04 to 9.2) as compared to AESR 10.2 (0.71 to 3.33) whereas high ESP was observed in pedon 4 and ranged from 1.63 to 12.98 which may be due to accelerated rate of formation and accumulation of pedogenic calcium carbonate in arid climate. EMP of the pedons ranged from 19.3 to 58.5 (AESR 6.3) and 9.4 to 53.2 (AESR 10.2) and SAR of the pedons (except pedon 4) in AESR 6.3 ranged from 0.43 to 4.95 and in AESR 10.2, it ranged from 0.24 to 1.59. Pedon 4 had maximum SAR that ranged from 0.74 to 8.4.

Macronutrients (available nitrogen, phosphorus and potassium) of the studied soils determined were at 0-20 cm depth. Available nitrogen was observed to be low in all the soils. Available P content was low in the soils P1, P2, P3, P4, P5 and P10 and medium in soils P6, P7, P8, P9, P11 and P12. Available K content was found to be high

in all the soils. DTPA-extractable micronutrients viz., iron, zinc, manganese and copper were found to decrease with depth at 0-20 cm, 20-40 cm, 40-60 cm, 60-80 cm and 80-100 cm in soils of both the AESRs.

Biological properties

The biological properties of the pedons in both the AESRs varied significantly at 5% level viz., SMBC (6.21), DHA (0.83), soil respiration (0.78), mineralizable nitrogen (4.33) and particulate organic matter (0.35). In AESR 6.3, among the six soils, the bacterial population was the highest in P6 (6.5 X 10^5 cfu g^{-1}) and the lowest was recorded in P4 (5.6 X10^5 cfu g^{-1}). The fungal population was highest in P6 (6.2 X 10^5 cfu g^{-1}) and the lowest in P4 (5.4 X10^5 cfu g^{-1}). The actinomycetes populations were found to be highest in P6 (5.4 X10^5 cfu g^{-1}) and lowest in P4 (4.9 X10^5 cfu g^{-1}). In AESR 10.2, among the six soils, the bacterial population was highest in P10 (6.8 X10^5 cfu g^{-1}) and the lowest in P8 (5.3 X10^5 cfu g^{-1}). The fungal population was highest in P10 (6.9 X10^5 cfu g^{-1}) and the lowest in P9 (5.2 X10^5 cfu g^{-1}). In case of actinomycetes populations were found to be highest in P10 (3.9X10^5 cfu g^{-1}) and lowest in P11 (3.0 X10^5 cfu g^{-1}). In case of microbial diversity, P5 (AESR 6.3) and P8 (AESR 10.2) were richest with respect to number of different fungal and bacterial species and they were also found to be high in their relative abundance (evenness).

Seed cotton yield

In terms of seed cotton yield, pedon 3 in AESR 6.3 and pedon 12 in AESR 10.2 had highest average yield of 29 q/ha and 35 q/ha respectively.

Soil quality assessment

For determination of SQ, MDS was developed using two approaches, one using expert knowledge and the other using statistical approach namely, pearson's correlation and Principal Component Analysis (PCA). The MDS developed through expert knowledge comprised 5 soil attributes, 3 physical (depth, clay and sHC), 1 each

chemical (ESP) and biological (SMBC) property of soils. As land evaluation method of SQ assessment focuses on physical and chemical soil properties and ignores biological ones, so for fuzzy modeling-based method 4 soil attributes comprising only physical (depth, clay and sHC) and chemical (ESP) properties of soils were therefore, used. For statistical method of MDS development, pearson's correlation matrix was developed between average yield of cotton crop and soil properties and highly weighted factor loadings were considered in the final MDS viz., PC1 included depth, clay, exchangeable Mg and nitrogen mineralization; PC2 included OC and SMBC; PC3 includes sHc; PC4 includes DHA and PC5 includes BS%.

SQ assessment was made by conventional method (RSQI), fuzzy modeling-based mathematical method (CSI) both using MDS developed by expert knowledge and PCA-based method (SQI) after developing MDS for each of them. It was observed that in case of all the three methods, Pedon 3 from AESR 6.3 with RSQI of 72.5, CSI of 79.6 and SQI of 1.63 and pedon 12 from AESR 10.2 with RSQI of 87.5, CSI of 80.3 and SQI of 1.85 were the best quality soils.

The correlation of SQIs with average yield in case of AESR 6.3 was found to be higher in PCA- based method (R^2= 0.86**) as compared to that in conventional method (R^2= 0.81) and fuzzy modelling-based method (R^2= 0.71) with an outlier, pedon 6. The correlation of SQIs with average yield in case of AESR 10.2 was found to be higher in the conventional method (R^2=0.90**) as compared to that in fuzzy modelling-based (R^2= 0.82**) and PCA based methods (R^2= 0.79) with an outlier, pedon 11.

Conclusion

- In case of large datasets, use of Pearson's correlation followed by principal component analysis was found to be an effective data reduction tool. This facilitated proper identification of mutually exclusive and locally relevant minimum datasets of physical, chemical and biological indicators for soil quality assessment.
- Of all the three methods used for soil quality assessment, the PCA-based method was identified as the best method for AESR 6.3 as evidenced by significant correlation of quality indices of soil with cotton yield (R^2=0.86**). On the other hand, the conventional method was identified as the best method for AESR 10.2 (R^2= 0.93**). Moreover, it was easy to use and was also less time consuming as it did not involve complex computations (like the ones in fuzzy modelling-based method and PCA-based method).
- Whenever we have such datasets (as used in the present investigation) for similar agroecological setups, we can compute soil quality indices by using the best identified method for assessing and monitoring soil quality. Having mentioned this, more studies will, however, need to be conducted before each of these two methods could be recommended as a standard method of soil quality assessment in the respective similar agroecological setup. Once this is done, the soil quality indices could also be effectively used to determine the future course of action for sustaining and improving the quality of soils.

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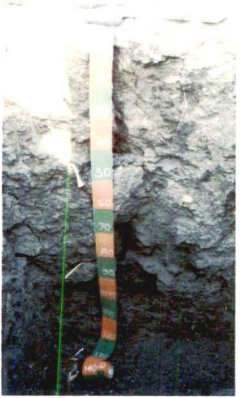
Place : Akola
Date: 6 / 5 / 2014

Signature of the student

ANNEXURE I

Description of Pedons

Pedon No. 1





Location	:	Village Dongargaon, Teh. Akola, Dist. Akola
Lattitude	:	$20^{0}42'13"$ N
Longitude	:	$76^{0}56'55"$ E
Elevation	:	296 m above MSL
Geology	:	Basalt
Physiography	:	Undulating plain
Parent material	:	Basaltic alluvium
Slope	:	0-1per cent
Drainage	:	Moderately well drained
Run-off	:	Medium

Ground water Depth	:	Above 10 m
Flooding	:	No
Climate	:	Semi-arid
Natural vegetation	:	Ber, Neem, Babool
Land use	:	Cotton, Tur
Classification	:	Fine, smectitic (calcareous), hyperthermic Typic Haplusterts
Remarks	:	2-3 cm wide cracks extended upto 90cm

Horizon		Description
Ap	0-17 cm	Very dark grayish brown (10 YR 3/2) clay; moderate medium subangular blocky structure; hard, friable, sticky and plastic; many medium roots; many fine pores; many fine nodules; strong effervescence; moderately alkaline (pH 8.5); clear smoothy boundary.
Bw1	17-49 cm	Very dark grayish brown (10 YR 3/2) clay; moderate medium subangular blocky structure; hard friable sticky and plastic; many fine medium roots; many fine pores; common fine nodules; strong effervescence; moderately alkaline (pH 8.5); gradual smoothy boundary.
Bw2	49-84 cm	Dark grayish brown (10 YR 4/2) clay; strong medium angular blocky structure with pressure faces; firm sticky and plastic; few common, very fine roots; common medium nodules; voilent effervescence; strongly alkaline (pH 8.8); gradual smoothy boundary.
Bss1	84-107 cm	Dark grayish brown (10 YR 4/2) clay; strong medium angular blocky structure with

		slickensides; firm very sticky and very plastic; few common, very fine roots; common medium nodules; voilent effervescence; strongly alkaline (pH 8.8); gradual smoothy boundary.
Bss2	107-150+ cm	Dark grayish brown (10 YR 4/2) clay; strong medium angular blocky structure with slickensides; firm very sticky and very plastic; few, very fine roots; common medium nodules; voilent effervescence; strongly alkaline (pH 8.8).

Pedon No. 2





Location	:	Village Sonori, Teh. Akola, Dist. Akola
Lattitude	:	$20^0 43' 23"$ N
Longitude	:	$76^0 20' 25"$ E
Elevation	:	315 m above MSL
Geology	:	Basalt
Physiography	:	Very gently sloping upland
Parent material	:	Weathered Basalt
Slope	:	1-3 per cent
Drainage	:	well drained
Run-off	:	Medium
Erosion	:	Moderate
Ground water Depth	:	Above 10 m
Flooding	:	No
Climate	:	Semi-arid
Natural vegetation	:	Neem, Babool

Land use	:	Cotton and vegetables
Classification	:	Loamy, smectitic, hyperthermic Lithic Haplustepts

Horizon		**Description**
Ap	0-19 cm	Dark brown (10 YR 3/3) clay loam; moderate medium subangular blocky structure; slightly hard friable sticky and plastic; few medium roots; many fine pores; few fine nodules; moderately alkaline (pH 8.1); clear smoothy boundary.
Bw	19-43 cm	Dark grayish brown (10 YR 4/2) silty clay; strong medium angular blocky structure; friable sticky and plastic; few and very fine roots; moderately alkaline (pH 8.3).
Cr	43+ cm	Weathered basalt

Pedon No. 3



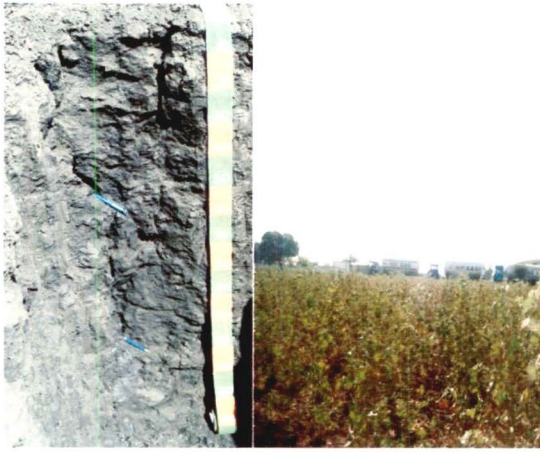


Location	:	Village Mana, Teh. Murtizapur, Dist. Akola
Lattitude	:	20046'20" N
Longitude	:	76028'30" E
Elevation	:	307 m above MSL
Geology	:	Basalt
Physiography	:	Undulating plain
Parent material	:	Basaltic Alluvium
Slope	:	0-1 per cent
Drainage	:	Moderately well drained
Run-off	:	Medium
Erosion	:	Moderate
Ground water Depth	:	Above10 m
Flooding	:	No
Climate	:	Semi-arid

Natural vegetation	:	Neem, Subabul, Gulmohar, Ber
Land use	:	Cotton and Tur, Wheat
Classification	:	Fine, smectitic (calcareous), hyperthermic Typic Haplusterts
Remarks	:	2 -3 cm wide cracks extend upto 78 cm

Horizon		Description
Ap	0-15 cm	Very dark grayish brown (10 YR 3/2) clay; moderate medium subangular blocky structure; hard friable sticky and plastic; many fine and coarse roots; many fine pores; many fine nodules; strong effervescence; moderately alkaline (pH 8.5); clear smoothy boundary.
Bw	15-45 cm	Dark grayish brown (10 YR 4/2) clay; moderate medium subangular blocky structure with pressure faces; hard friable sticky and plastic; many fine roots; many fine and medium nodules; strong effervescence; moderately alkaline (pH 8.5); gradual smoothy boundary
Bss1	45-83 cm	Dark grayish brown (10 YR 4/2) clay; moderate medium angular blocky structure with slickensides; firm very sticky and vey plastic; few common, very fine roots; common, fine and medium nodules; strong effervescence; moderately alkaline (pH 8.5); gradual smoothy boundary.
Bss2	83-150+ cm	Brown (10 YR 4/3) clay; strong medium angular blocky structure with slickensides; firm very sticky and very plastic; few common and very fine roots; common medium nodules; voilent effervescence; moderetly alkaline (pH 8.5).

Pedon No. 4



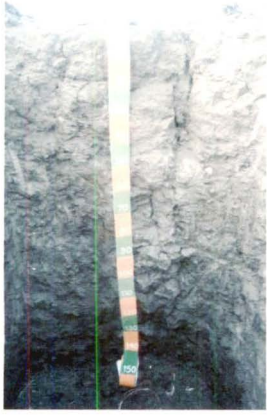
Location	:	Village Vallabhnagar, Teh. Akola, Dist. Akola
Lattitude	:	20050'17" N
Longitude	:	76059'18" E
Elevation	:	273 m above MSL
Geology	:	Basalt
Physiography	:	Undulating plain
Parent material	:	Basaltic Alluvium
Slope	:	0-1per cent
Drainage	:	Imperfectly drained
Run-off	:	Medium
Erosion	:	Moderate
Ground water Depth	:	Below 10 m

Flooding	:	No
Climate	:	Semi-arid
Natural vegetation	:	Neem, Subabul, Pipal, Babool, Adulsa
Land use	:	Cotton and Tur, Wheat
Classification	:	Very-fine, smectitic (sodic), hyperthermic Typic Haplusterts
Other features	:	2-5 cm wide crack extend upto 30cm.

Horizon		Description
Ap	0-19 cm	Very dark grayish brown (10 YR 3/2) clay; moderate medium subangular blocky structure; hard friable sticky and plastic; many medium roots; few many, very fine pores; many coarse nodules; violent effervescence; moderately alkaline (pH 8.5); clear smooth boundary
Bw1	19-46 cm	Very dark grayish brown (10 YR 3/2) clay; moderate medium subangular blocky structure with pressure faces; hard friable sticky and plastic; many medium roots; few many, very fine pores; many coarse nodules; violent effervescence; strongly alkaline (pH 8.6); clear smooth boundary.
Bss1	71-98 cm	Very dark grayish brown (10 YR 3/2) clay; moderate medium subangular blocky structure with slickensides; firm very sticky and very plastic; few common, very fine roots; few common, fine medium nodules; strong effervescence; strongly alkaline (pH 8.8); gradual smooth boundary.
Bss2	98-120 cm	Very dark grayish brown (10 YR 3/2) clay; moderate medium subangular blocky structure with slickensides; firm very sticky and very plastic; few, very fine roots; many few, very fine and fine coarse nodules; strong effervescence; strongly alkaline (pH 8.6); gradual smooth boundary.

Bss3	120-143 cm	Very dark grayish brown (10 YR 3/2) clay; moderate medium subangular blocky structure with slickensides; firm very sticky and very plastic; few, very fine roots; few, very fine and fine coarse nodules; strong effervescence; moderately alkaline (pH 8.5).

Pedon No. 5





Location	:	Village Rohana, Teh. Akola, Dist. Akola
Lattitude	:	$20^0$52'26" N
Longitude	:	$76^0$45'21" E
Elevation	:	276 m above MSL
Geology	:	Basalt
Physiography	:	Undulating plain
Parent material	:	Basaltic Alluvium
Slope	:	1-3 per cent
Drainage	:	Moderately well drained
Run-off	:	Medium
Erosion	:	Moderate
Ground water Depth	:	Above 10 m
Flooding	:	No

Climate	:	Semi-arid
Natural vegetation	:	Neem, Gulmohar, Babool,
Land use	:	Cotton and Tur, Wheat
Classification	:	Very-fine, smectitic (calcareous), hyperthermic Typic Haplusterts
Remarks	:	0.5-1 cm wide crack from 60 cm to 80 cm

Horizon		Description
Ap	0-17 cm	Very dark grayish brown (10 YR 3/2) clay; moderate medium subangular blocky structure; hard friable sticky and plastic; many medium roots; many fine pores; many coarse nodules; strong effervescence; moderately alkaline (pH 8.2); clear smooth boundary.
Bw	17-43 cm	Very dark grayish brown (10 YR 3/2) clay; moderate medium subangular blocky structure with pressure faces; hard friable sticky and plastic; many fine and medium roots; few many, very fine pores; few, very fine nodules; strong effervescence; moderately alkaline (pH 8.4); gradual smoothy boundary.
Bss1	43-69 cm	Very dark grayish brown (10 YR 3/2) clay; moderate medium subangular blocky structure with weakly developed slickensides; firm sticky and plastic; few, common and very fine roots; few many, very fine pores; few, very fine nodules; slight effervescence; moderately alkaline (pH 8.4); gradual smoothy boundary.
Bss2	69-98 cm	Brown (10 YR 4/3) clay; strong medium angular blocky structure with slickensides; firm sticky and plastic; few, common and very fine roots; few many, fine nodules; slight effervescence; moderately alkaline (pH 8.5); gradual smoothy boundary.

Bss3	98-120+ cm	Brown (10 YR 4/3) clay; strong medium angular blocky structure with slickensides; firm sticky and plastic; few very fine roots; few, very fine nodules; slight effervescence; moderately alkaline (pH 8.6).

Pedon No. 6





Location	:	Village Popatkhed, Teh. Akot, Dist. Akola
Lattitude	:	$21^0 11' 59''$ N
Longitude	:	$76^0 59' 57''$ E
Elevation	:	417 m above MSL
Geology	:	Basalt
Physiography	:	Undulating plain
Parent material	:	Basaltic Alluvium
Slope	:	1-3 per cent
Drainage	:	Moderately well drained
Run-off	:	Medium
Erosion	:	Moderate
Ground water Depth	:	Above 10 m

Flooding	:	No
Climate	:	Semi-arid
Natural vegetation	:	Neem, Palas, Babool,
Land use	:	Cotton and Tur, Wheat
Classification	:	Very-fine, smectitic (calcareous) hyperthermic Vertic Haplustepts

Horizon		Description
Ap	0-17 cm	Very dark grayish brown (10 YR 3/2) clay; moderate medium subangular blocky structure; slightly hard friable sticky and plastic; many fine and medium roots; few many, very fine pores; few many very fine nodules; slight effervescence; moderately alkaline (pH 8.1); clear smooth boundary.
Bw1	17-35 cm	Very dark grayish brown (10 YR 3/2) clay; moderate medium subangular blocky structure; firm very sticky and very plastic; many fine and medium roots; few common, very fine nodules; slight effervescence; moderately alkaline (pH 8.1); gradual smooth boundary.
Bw2	35-70 cm	Very dark grayish brown (10 YR 3/2) clay; moderate medium subangular blocky structure with pressure faces; firm very sticky and very plastic; few common, very fine roots; few, very fine nodules; slight effervescence; moderately alkaline (pH 8.1); gradual smooth boundary.
Bw3	70-91 cm	Very dark grayish brown (10 YR 3/2) clay; moderate medium subangular blocky structure with pressure faces; firm very sticky and very plastic; few, very fine roots; few, very fine nodules; slight effervescence; moderately alkaline (pH 8.1).

Pedon No. 7





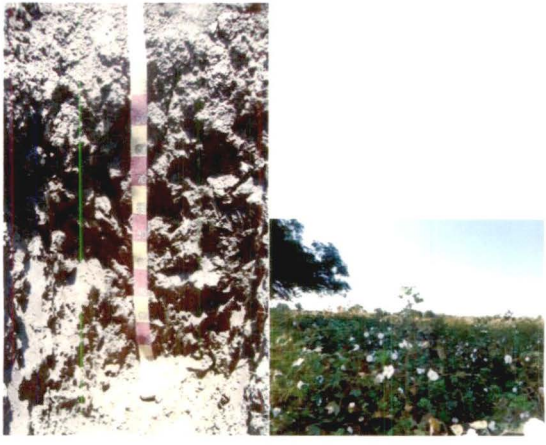
Location	:	Village Paradi, Teh. Narkhed, Dist. Nagpur
Lattitude	:	21°27 00" N
Longitude	:	78°32 16" E
Elevation	:	409 m above MSL
Geology	:	Basalt
Physiography	:	Alluvium Plain
Parent material	:	Weathered basalt
Slope	:	1-3 per cent
Drainage	:	Moderately well drained
Run-off	:	Medium
Erosion	:	Very slow
Ground water Depth	:	Above10 m

Flooding	:	No
Climate	:	Sub humid
Natural vegetation	:	Neem, Palas, Bamboo, Karanj, Mango,
Land use	:	Cotton, wheat
Classification	:	Fine, smectitic (calcareous), hyperthermic Typic Haplusterts
Remarks	:	Pressure faces between 40-90 cm and intersecting slickensides at 85 cm depth

Horizon		Description
Ap	0-15 cm	Very dark grayish brown (10 YR 3/2) clay; moderate medium subangular blocky structure; hard friable sticky and plastic; many, medium roots; many, fine pores; few many, very fine nodules; slight effervescence; strongly alkaline (pH 8.7); clear smooth boundary.
Bw1	15-31 cm	Dark grayish brown (10 YR 4/2) clay; moderate medium subangular blocky structure; hard friable sticky and plastic; many, medium roots; few many, very fine pores; few common, very fine nodules; slight effervescence; strongly alkaline (pH 8.7); gradual smooth boundary.
Bw2	31-52 cm	Dark brown (10 YR 3/3) clay; moderate medium subangular blocky structure with pressure faces; hard friable sticky and plastic; common fine, medium roots; few many, very fine pores; few common, very fine nodules; slight effervescence; strongly alkaline (pH 8.7); gradual smooth boundary.
Bss1	52-83 cm	Dark grayish brown (10 YR 4/2) clay; moderate medium subangular blocky structure with weakly developed slickensides; firm very sticky and very

		plastic; few common, fine medium roots; few common, very fine nodules; slight effervescence; strongly alkaline (pH 8.7); gradual smooth boundary.
Bss2	83-115 cm	Dark grayish brown (10 YR 4/2) clay; strong medium angular blocky structure with slickensides; firm very sticky and very plastic; few common, very fine roots; medium few, fine medium nodules; strong effervescence; strongly alkaline (pH 8.8); gradual smooth boundary.
Bss3	115-130 cm	Dark grayish brown (10 YR 4/2) clay; strong medium angular blocky structure with slickensides; firm very sticky and very plastic; few, very fine roots; medium few, fine medium nodules; strong effervescence; strongly alkaline (pH 8.7); gradual smooth boundary.
Bss4	130-150+ cm...	Dark grayish brown (10 YR 4/2) clay; strong medium angular blocky structure with slickensides; firm very sticky and very plastic; few, very fine roots; medium few, fine medium nodules; strong effervescence; strongly alkaline (pH 8.7).

Pedon 8



Location	:	Village Mangali, Teh. Higana, Dist. Nagpur
Lattitude	:	$21^0 04' 04"$ N
Longitude	:	$78^0 55' 17"$ E
Elevation	:	312 m above MSL
Geology	:	Basalt
Physiography	:	Upper alluvium plain
Parent material	:	Weathered Basalt (calcareous)
Slope	:	1-3 per cent
Drainage	:	Moderately well drained
Run-off	:	Medium
Erosion	:	Very slow
Ground water Depth	:	Above 10 m
Flooding	:	No

Climate	:	Sub humid
Natural vegetation	:	Neem, Palas, Karanj, Ashoka,
Land use	:	Cotton, wheat
Classification	:	Very fine, smectitic (calcareous), hyperthermic Typic Haplusterts
Remarks	:	1-2 cm wide cracks from 35 cm to 58 cm, sharp slickensides at 105 cm

Horizon		Description
Ap	0-10 cm	Very dark grayish brown (10 YR 3/2) clay; moderate medium subangular blocky structure; very hard very friable slight sticky; many medium roots; few many, very fine pores; few common, very fine nodules; slight effervescence; moderately alkaline (pH 8.4); clear smooth boundary.
Bw	10-32 cm	Very dark grayish brown (10 YR 3/2) clay; moderate medium subangular blocky structure with pressure faces; very hard, friable sticky and plastic; many medium roots; few many, very fine pores; few common, very fine nodules; slight effervescence; strongly alkaline (pH 8.6); clear smooth boundary.
Bss1	32-54 cm	Very dark grayish brown (10 YR 3/2) clay; strong medium angular blocky structure with weakly developed slickensides; very hard, friable sticky and plastic; common fine medium roots; few common, very fine nodules; slight effervescence; strongly alkaline (pH 8.6); gradual smooth boundary.
Bss2	54-81 cm	Very dark grayish brown (10 YR 3/2) clay; strong medium angular blocky structure with slickensides; very hard, friable sticky and plastic; few common,

		fine medium roots; many few, fine medium nodules; strong effervescence; strongly alkaline (pH 8.6); gradual smooth boundary.
Bss3	81-110 cm	Very dark grayish brown (10 YR 3/2) clay; strong medium angular blocky structure with slickensides; firm very sticky and very plastic; few common, very fine roots; many few, fine medium nodules; strong effervescence; strongly alkaline (pH 8.6); gradual smooth boundary.
Bss4	110-140 cm	Very dark grayish brown (10 YR 3/2) clay; strong medium angular blocky structure with slickensides; firm very sticky and very plastic; few, very fine roots; many few, fine medium nodules; strong effervescence; strongly alkaline (pH 8.7); gradual smooth boundary.
Bc	140+ cm	Weathered basalt

Pedon 9



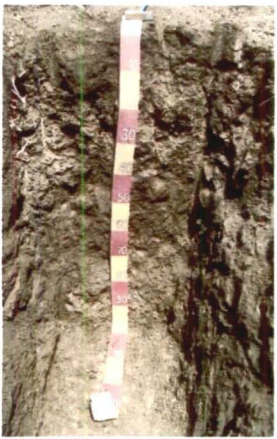


Location	:	Village Waroda, Teh. Kalmeshwar, Dist. Nagpur
Lattitude	:	$21^{0}15'43"$ N
Longitude	:	$78^{0}54'36"$ E
Elevation	:	339 m above MSL
Geology	:	Basalt
Physiography	:	Pediment
Parent material	:	Weathered Basalt
Slope	:	1-3 per cent
Drainage	:	Well drained
Run-off	:	Medium
Erosion	:	Moderate
Ground water Depth	:	Above 10 m
Flooding	:	No
Climate	:	Sub humid

Natural vegetation	:	Neem, Babool, Teak
Land use	:	Cotton and vegetables
Classification	:	Loamy, smectitic, hyperthermic Lithic Haplustepts

Horizon		Description
Ap	0-10 cm	Dark brown (10 YR 3/3) clay loam; moderate medium subangular blocky structure; slightly hard, friable sticky and plastic; few fine roots; few, very fine pores; moderately alkaline (pH 8.3); clear smooth boundary.
Bw	10-35 cm	Dark brown (10 YR 3/3) clay loam; moderate medium subangular blocky structure; friable sticky and plastic; few very fine nodules; nil to slight effervescences; moderately alkaline (pH 8.3); clear smooth boundary.
Cr	35-50 cm	Weathered Basalt
R	50+ cm	Parent material

Pedon 10





Location	:	Village Pevatha, Teh. Nagpur, Dist. Nagpur
Lattitude	:	21°02'25" N
Longitude	:	79°05'14" E
Elevation	:	299 m above MSL
Geology	:	Basalt
Physiography	:	Pediment
Parent material	:	Weathered Basalt
Slope	:	1-3 per cent
Drainage	:	Well drained
Run-off	:	Medium
Erosion	:	Moderate
Ground water Depth	:	Above 10 m

Flooding	:	No
Climate	:	Sub humid
Natural vegetation	:	Neem, Subabool, Palas
Land use	:	Cotton, Tur
Classification	:	Very-fine, smectitic (calcareous), hyperthermic Vertic Haplustepts

Horizon		Description
Ap	0-15 cm	Very dark grayish brown (10 YR 3/2) clay; moderate medium subangular blocky structure; hard friable sticky and plastic; many medium roots; many fine pores; few, very fine nodules; moderately alkaline (pH 8.5); clear smooth boundary.
Bw1	15-35 cm	Very dark grayish brown (10 YR 3/2) clay; moderate medium subangular blocky structure; friable sticky and plastic; common fine medium roots; many fine pores; very fine nodules; nil to slight effervescence; moderately alkaline (pH 8.5); clear smooth boundary.
Bw2	35-58 cm	very dark grayish brown (10 YR 3/2) clay; moderate medium subangular blocky structure; firm sticky and plastic; few common, fine medium roots; many few, very fine nodules; nil to slight effervescence; moderately alkaline (pH 8.5); clear smooth boundary.
Bw3	58-85 cm	dark brown (10 YR 3/3) clay; strong medium angular blocky structure; firm sticky and plastic; few common, very fine roots; many few, very fine nodules; slight effervescence; strongly alkaline (pH 8.6); clear smooth boundary.

Bw4	85-108 cm	dark brown (10 YR 3/3) clay; strong medium angular blocky structure; firm sticky and plastic; few, very fine roots; many few, very fine nodules; strong effervescence; strongly alkaline (pH 8.6).

Pedon 11





Location	:	Village Asola, Teh. Hingana, Dist. Nagpur
Lattitude	:	$21^{0}52'09"$ N
Longitude	:	$78^{0}54'08"$ E
Elevation	:	297m above MSL
Geology	:	Basalt
Physiography	:	Undulating plain
Parent material	:	Weathered Basalt
Slope	:	1-3 per cent
Drainage	:	Well drained
Run-off	:	Medium
Erosion	:	Moderate
Ground water Depth	:	Above 10 m
Flooding	:	No
Climate	:	Sub humid

Natural vegetation	:	Neem, Subabool, Palas
Land use	:	Cotton, Tur
Classification	:	Clayey, smectitic (calcareous), hyperthermic Lithic Ustorthents

Horizon		**Description**
Ap	0-15 cm	very dark grayish brown (10 YR 3/2) clay; moderate medium subangular blocky structure; hard friable sticky and plastic; few common, very fine roots; few fine pores; many few, very fine nodules; strong effervescence; moderately alkaline (pH 8.3); clear smooth boundary.
Cr	15-40+ cm	weathered Basalt

Pedon 12





Location	:	Village Shiva, Teh. Nagpur, Dist. Nagpur
Lattitude	:	21^{0}07'22" N
Longitude	:	78^{0}44'40" E
Elevation	:	393 m above MSL
Geology	:	Basalt
Physiography	:	Lower pediment
Parent material	:	Basaltic alluvium
Slope	:	1-3 per cent
Drainage	:	Well drained
Run-off	:	Medium
Erosion	:	Moderate
Ground water Depth	:	Above 10 m
Flooding	:	No
Climate	:	Sub humid

Natural vegetation	:	Neem, Bamboo, Mango, Karanj
Land use	:	Cotton, Tur, wheat
Classification	:	Fine, smectitic (calcareous), hyperthermic Vertic Haplustepts

Horizon		Description
Ap	0-10 cm	Very dark grayish brown (10 YR 3/2) clay; moderate medium subangular blocky structure; hard friable sticky and plastic; many medium roots; few many, very fine pores; few common, very fine nodules; slight effervescence; moderately alkaline (pH 8.4); clear smooth boundary.
Bw1	10-38 cm	Very dark grayish brown (10 YR 3/2) clay; moderate medium subangular blocky structure with pressure faces; hard friable sticky and plastic; many medium roots; few many, very fine pores; few common, very fine nodules; slight effervescence; strongly alkaline (pH 8.6); diffuse smooth boundary.
Bw2	38-59 cm	Very dark grayish brown (10 YR 3/2) clay; moderate medium subangular blocky structure with pressure faces; friable sticky and plastic; few common fine coarse roots; few many, few common, very fine nodules; slight effervescence; strongly alkaline (pH 8.6); diffuse smooth boundary.

Bw3	59-82 cm	Very dark grayish brown (10 YR 3/2) clay; moderate medium subangular blocky structure with pressure faces; friable sticky and plastic; few common very fine roots; few common, very fine nodules; slight effervescence; moderately alkaline (pH 8.5); diffuse smooth boundary.
Bw4	82-100 cm	Very dark grayish brown (10 YR 3/2) clay; strong medium angular blocky structure with pressure faces; very firm very sticky and very plastic; few very fine roots; few common, very fine nodules; slight effervescence; moderately alkaline (pH 8.5); diffuse smooth boundary.
Bw5	100-150+ cm	Very dark grayish brown (10 YR 3/2) clay; strong medium angular blocky structure with pressure faces; very firm very sticky and very plastic; few very fine roots; few common, very fine nodules; strong effervescence; strongly alkaline (pH 8.6).

ANNEXURE II

A. Pearson's correlation

	Cotton yield	depth	sand	silt	clay	BD	FC	WP	AWC	sHC
Cotton yield	1									
depth	0.755	1								
sand	-0.511	-0.688	1							
silt	0.183	0.361	-0.045	1						
clay	0.399	0.494	-0.895	-0.402	1					
BD	0.701	0.597	-0.760	-0.132	0.751	1				
FC	0.249	0.229	-0.800	-0.415	0.906	0.625	1			
WP	0.181	0.100	-0.669	-0.562	0.852	0.572	0.959	1		
AWC	0.307	0.479	-0.711	0.277	0.520	0.410	0.520	0.256	1	
sHC	-0.505	-0.341	0.534	0.061	-0.503	-0.532	-0.583	-0.452	-0.624	1

Contd..

	Cotton yield	pH	EC	OC	CaCO3	Ca	Mg	Na	K	CEC	Sum Bases	BS	SAR	ESP	EMP
pH	0.457	1													
EC	-0.377	-0.066	1												
OC	-0.385	-0.533	0.460	1											
$CaCO_3$	0.305	0.570	0.073	-0.138	1										
Ca	-0.036	-0.179	-0.146	0.616	-0.045	1									
Mg	0.668	0.526	-0.143	-0.423	0.289	-0.302	1								
Na	0.276	0.347	0.607	-0.097	0.146	-0.369	0.459	1							
K	-0.375	-0.517	0.367	0.244	-0.162	-0.078	-0.382	-0.160	1						
CEC	0.275	0.168	-0.155	0.436	0.222	0.884	0.134	-0.137	-0.246	1					
Sum Bases	0.185	0.097	-0.129	0.467	0.106	0.924	0.057	-0.141	-0.226	0.979	1				
BS	-0.492	-0.417	0.096	0.185	-0.638	0.222	-0.388	-0.035	0.091	-0.080	0.120	1			
SAR	0.364	0.439	0.556	-0.213	0.293	-0.493	0.532	0.958	-0.232	-0.222	-0.251	-0.195	1		
ESP	0.230	0.304	0.620	-0.186	0.143	-0.564	0.408	0.963	-0.115	-0.366	-0.373	-0.073	0.975	1	
EMP	0.174	0.373	0.098	-0.650	0.143	-0.912	0.581	0.472	-0.181	-0.686	-0.712	-0.169	0.608	0.619	1

Contd..

	Cotton yield	N	P	K	Fe	Mn	Zn	Cu	SMBC	DHA	CO2	H	D	E1	E2	POM	N Min
N	-0.622	1															
P	-0.379	0.767	1														
K	-0.392	0.394	0.589	1													
Fe	-0.508	0.688	0.635	0.264	1												
Mn	-0.644	0.805	0.615	0.394	0.650	1											
Zn	-0.501	0.727	0.721	0.283	0.679	0.676	1										
Cu	-0.321	0.683	0.910	0.377	0.750	0.581	0.826	1									
SMBC	0.115	0.263	0.477	0.011	0.390	0.184	0.224	0.609	1								
DHA	-0.530	0.423	0.095	0.100	0.221	0.798	0.304	0.047	-0.089	1							
CO_2	-0.663	0.374	0.418	0.531	0.339	0.653	0.420	0.346	0.100	0.608	1						
H	0.043	-0.352	-0.504	-0.020	-0.195	-0.124	-0.326	-0.566	-0.297	0.284	0.252	1					
D	-0.007	0.323	0.564	0.068	0.230	0.132	0.330	0.619	0.339	-0.307	-0.198	-0.985	1				
E1	0.060	-0.366	-0.578	-0.091	-0.208	-0.166	-0.354	-0.610	-0.295	0.259	0.166	0.989	-0.994	1			
E2	0.008	-0.326	-0.572	-0.066	-0.239	-0.137	-0.344	-0.629	-0.346	0.304	0.196	0.984	-1.000	0.993	1		
POM	0.042	-0.351	-0.501	-0.016	-0.194	-0.123	-0.324	-0.564	-0.295	0.283	0.254	1.000	-0.985	0.989	0.983	1	
N Min	0.472	-0.267	-0.223	-0.391	-0.473	-0.266	-0.355	-0.269	0.389	0.011	-0.042	0.327	-0.314	0.322	0.313	0.326	1

B. Micronutrient status of soils

Depth (cm)	Available Fe (mg/kg)	Available Zn (mg/kg)	Available Mn (mg/kg)	Available Cu (mg/kg)
Pedon 1				
0-20	6.1	0.38	4.6	2.54
20-40	5.0	0.3	4.18	2.24
40-60	3.0	0.28	3.8	2.16
60-80	1.5	0.22	3.26	1.82
80-100	1.3	0.16	3.26	1.48
Pedon 2				
0-20	9.0	0.6	9.8	3.14
20-40	5.7	0.28	3.16	1.68
Pedon 3				
0-20	5.6	0.24	4	1.64
20-40	4.3	0.2	3.18	1.58
40-60	2.1	0.16	2.68	1.52
60-80	1.7	0.14	1.28	1.46
Pedon 4				
0-20	7.7	0.2	2.86	1.6
20-40	6.6	0.16	2.82	1.66
40-60	4.4	0.18	2.84	1.7
60-80	3.2	0.18	3.22	1.7
80-100	1.4	0.16	3.96	1.92
Pedon 5				
0-20	6.7	0.28	4.8	2.18
20-40	4.9	0.14	3.42	2.09
40-60	2.0	0.12	2.96	1.86
60-80	1.9	0.14	2.6	1.82
80-100	0.2	0.14	1.94	1.7

Contd.....

Depth (cm)	Available Fe (mg/kg)	Available Zn (mg/kg)	Available Mn (mg/kg)	Available Cu (mg/kg)
Pedon 6				
0-20	7.1	0.5	9.4	4.02
20-40	5.7	0.28	7.4	2.92
40-60	3.8	0.26	5.08	2.84
60-80	1.4	0.28	4.16	2.64
Pedon 7				
0-20	6.7	1.54	13.2	6.1
20-40	6.3	1.12	5.62	3.54
40-60	5.2	0.2	5.16	2.32
60-80	2.7	0.18	4.52	2
80-100	1.3	0.18	4.2	1.98
Pedon 8				
0-20	6.5	0.58	12.6	2.18
20-40	4.5	0.36	11.2	1.86
40-60	2.7	0.28	8.4	1.42
60-80	1.3	0.08	4.48	1.14
80-100	1.2	0.12	3.4	1.26
Pedon 9				
0-20	8.1	0.52	8.2	4.48
20-40	7.2	0.58	4.8	3.64
Pedon 10				
0-20	6.0	0.4	11.4	1.34
20-40	4.6	0.22	10.1	1.3
40-60	3.1	0.26	9	1.3
60-80	2.6	0.26	7.8	1.18
80-100	1.4	0.12	3.8	1.26
Pedon 11				
0-20	9.0	0.72	14.2	3.8
Pedon 12				
0-20	8.1	0.74	15.5	4
20-40	6.5	0.52	12.2	3.56
40-60	4.6	0.4	10.4	3.14
60-80	3.0	0.26	9.2	2.98
80-100	2.7	0.28	8.6	2.1

Annexure III

Questionnaire for recording farmers' information

Pedon 1

1. Name of the farmer	Prakash B. Deshmukh
2. Location and address	At post - Dongargaon, Ta. Akola, Dist. Akola
3. Soil type (textural class and depth).	150 cm
4. Current cropping system-	Inter or mixed cropping Cotton, Tur (Kharif) Wheat (Rabi)
5. Change in cropping system during last 10 years	No
6. Type of farming	Rainfed
7. Methods of irrigation-	-
8. Crop wise information on the following aspects (for cotton) (8.1) Variety Name: Ankur 651 Bt (8.2) Sowing time – Second week of June Area - 5 Acre	
(8.3) Organic manure Name - FYM and compost Quantity applied - 1-2 cartload (Alternate year) Time of application - Before sowing Method of application - Broadcasting	
(8.4) Irrigation: No irrigation	
(8.5) Fertilizer – Nitrogen, Phosphorus and Potassium doses Dose - 30:30:0 kg NPK/ ha Source - Urea and DAP	
(8.6) How much residues left in field after harvesting (tones/ha) -	
(8.7) Crop yield: Normal year : 19.9 q/ha (2011-12) Worst year : 17.1 q/ha	
(8.8) Any other -	

Pedon 2

1. Name of the farmer	Mohammad Ismail Mohammad Ibrahim
2. Location and address	At Sonori Ta. Akola, Dist. Akola
3. Soil type (textural class and depth).	43 cm
4. Current cropping system-	Mixed cropping Cotton (Kharif) Vegetables (Seasonally)
5. Change in cropping system during last 10 years	No
6. Type of farming	Rainfed
7. Methods of irrigation-	Well
8. Crop wise information on the following aspects (for cotton) (8.1) Variety – Paras Bt (8.2) Sowing time – First week of July Area - 2 acre	
(8.3) Organic manure - Not applied	
(8.4) Irrigation: Frequent irrigation through well	
(8.5) Fertilizer – Nitrogen, Phosphorus and Potassium doses Dose - 20:20:0 kg NPK/ha Source –Urea and DAP	
(8.6) How much residues left in field after harvesting (tones/ha) –	
(8.7) Crop yield: Normal year : 14.4 q/ha (2011-12) Worst year : 10.5 q/ha	
(8.8) Any other -	

Pedon 3

1. Name of the farmer	Mohammad Ashpaq
2. Location and address	At post - Mana Ta. - Murtizapur, Dist. -Akola
3. Soil type (textural class and depth).	150 cm
4. Current cropping system-	Sequence cropping Cotton (Kharif) Gram (Rabi)
5. Change in cropping system during last 10 years	No
6. Type of farming	Rainfed
7. Methods of irrigation-	-
8. Crop wise information on the following aspects (for cotton) (8.1) Variety – Bollgourd II (8.2) Sowing time - Last week of June Area - 3 acre	
(8.3) Organic manure Name - Compost Quantity applied - 1-2 cartload (Alternate year) Time of application - Before sowing Method of application - Broadcasting	
(8.4) Irrigation: No irrigation	
(8.5) Fertilizer – Nitrogen, Phosphorus and Potassium doses Dose – 30:30:30 kg NPK/ha Source -Urea, DAP and MOP	
(8.6) How much residues left in field after harvesting (tones/ha) -	
(8.7) Crop yield: Normal year : 28 q/ha (2011-12) Worst year : 25.9 q/ha	
(8.8) Any other -	

Pedon 4

1. Name of the farmer	Ravindra Manikrao Patond
2. Location and address	At post - Vallabhnagar Ta. - Akola, Dist. -Akola
3. Soil type (textural class and depth).	143 cm
4. Current cropping system-	Mixed cropping Cotton and Tur (Kharif) Wheat (Rabi)
5. Change in cropping system during last 10 years	No
6. Type of farming	Rainfed
7. Methods of irrigation-	-
8. Crop wise information on the following aspects (for cotton) (8.1) Variety – Bt 9632 (8.2) Sowing time - Last week of June Area - 3 acre	
(8.3) Organic manure - Not applied	
(8.4) Irrigation: No irrigation	
(8.5) Fertilizer – Nitrogen, Phosphorus and Potassium doses Dose – 30:30:0 kg NPK/ ha Source - Urea and DAP	
(8.6) How much residues left in field after harvesting (tones/ha) -	
(8.7) Crop yield: Normal year : 17.1 q/ha (2011-12) Worst year : 12.5 q/ha	
(8.8) Any other -	

Pedon 5

1. Name of the farmer	Prabhakar Gite
2. Location and address	At post - Rohana Ta. - Akola, Dist. -Akola
3. Soil type (textural class and depth).	120 cm
4. Current cropping system-	Sequence cropping Cotton (Kharif) Gram (Rabi)
5. Change in cropping system during last 10 years	No
6. Type of farming	Rainfed
7. Methods of irrigation-	-
8. Crop wise information on the following aspects (for cotton) (8.1) Variety – Jay Bt (8.2) Sowing time - Last week of June Area - 3 acre	
(8.3) Organic manure Name - Compost Quantity applied - 7-8 ton (once in a three year) Time of application - Before sowing Method of application- Broadcasting	
(8.4) Irrigation: No irrigation	
(8.5) Fertilizer – Nitrogen, Phosphorus and Potassium doses Rate – 30:30:0 kg NPK /ha Source - Urea and DAS	
(8.6) How much residues left in field after harvesting (tones/ha) -	
(8.7) Crop yield: Normal year : 19.7 q/ha (2011-12) Worst year : 18.7 q/ha	
(8.8) Any other -	

Pedon 6

1. Name of the farmer	Ramdas Narayan Chaure
2. Location and address	At post - Popatkhed Ta. - Akot, Dist. -Akola
3. Soil type (textural class and depth).	91 cm
4. Current cropping system-	Intercropping Cotton + Tur (Kharif) Gram (Rabi)
5. Change in cropping system during last 10 years	No
6. Type of farming	Rainfed
7. Methods of irrigation-	-
8. Crop wise information on the following aspects (for cotton) (8.1) Variety – Swabhiman Bt (8.2) Sowing time - Last week of June Area - 2 acre	
(8.3) Organic manure Name - FYM Quantity applied - 10-12 ton (after every three year) Time of application - Before sowing Method of application- Broadcasting	
(8.4) Irrigation: No irrigation	
(8.5) Fertilizer - Nitrogen, Phosphorus and Potassium (NPK) Dose – 30:30:0 kg NPK /ha Source – Urea, DAP and SSP	
(8.6) How much residues left in field after harvesting (tones/ha) -	
(8.7) Crop yield: Normal year : 16.2 q/ha (2011-12) Worst year : 13.2 q/ha	
(8.8) Any other -	

Pedon 7

1. Name of the farmer	Muzif Vajir Sheikh
2. Location and address	At post - Pardi Ta. - Narkhed, Dist. -Nagpur
3. Soil type (textural class and depth).	150 cm
4. Current cropping system-	Mixed cropping Cotton and Soybean (Kharif) Gram (Rabi)
5. Change in cropping system during last 10 years	No
6. Type of farming	Rainfed
7. Methods of irrigation-	-
8. Crop wise information on the following aspects (for cotton) (8.1) Variety – Bramha Bt (8.2) Sowing time - First week of July Area - 7 acre	
(8.3) Organic manure Name - FYM Quantity applied - 10-12 ton (in alternate year) Time of application - Before sowing Method of application- Broadcasting	
(8.4) Irrigation: No irrigation	
(8.5) Fertilizer - Nitrogen, Phosphorus and Potassium (NPK) Dose – 30:30:0 kg NPK /ha and Source – Urea, DAP and SSP	
(8.6) How much residues left in field after harvesting (tones/ha) -	
(8.7) Crop yield: Normal year : 25.2 q/ha (2011-12) Worst year : 22.0 q/ha	
(8.8) Any other -	

Pedon 8

1. Name of the farmer	Dilip Shamrao Nighot
2. Location and address	At post - Mangli Ta. - Hingana, Dist. -Nagpur
3. Soil type (textural class and depth).	140 cm
4. Current cropping system-	Sequence cropping Cotton (Kharif) Gram (Rabi)
5. Change in cropping system during last 10 years	No
6. Type of farming	Rainfed
7. Methods of irrigation-	-
8. Crop wise information on the following aspects (for cotton) (8.1) Variety – Bt 630 (8.2) Sowing time - Last week of June Area - 6 acre	
(8.3) Organic manure Name - FYM Quantity applied - 4-5 ton (in alternate year) Time of application - Before sowing Method of application- Broadcasting	
(8.4) Irrigation: No irrigation	
(8.5) Fertilizer - Nitrogen, Phosphorus and Potassium (NPK) Dose – 30:30:0 kg NPK /ha Source – Urea, DAP and 18:18:10	
(8.6) How much residues left in field after harvesting (tones/ha) -	
(8.7) Crop yield: Normal year : 26.3 q/ha (2011-12) Worst year : 26 q/ha	
(8.8) Any other -	

Pedon 9

1. Name of the farmer	Vitthal Rajaramji Hiware
2. Location and address	At post - Waroda Ta. - Kalmeshwar, Dist. -Nagpur
3. Soil type (textural class and depth).	50 cm
4. Current cropping system-	Mixed cropping Cotton (Kharif) Vegetables (Seasonly)
5. Change in cropping system during last 10 years	No
6. Type of farming	Rainfed
7. Methods of irrigation-	-
8. Crop wise information on the following aspects (for cotton) (8.1) Variety – Paras Bt (8.2) Sowing time - Last week of June Area - 4 acre	
(8.3) Organic manure Name - FYM Quantity applied - 3-4 ton (in alternate year) Time of application - Before sowing Method of application- Broadcasting	
(8.4) Irrigation: No irrigation	
(8.5) Fertilizer - Nitrogen, Phosphorus and Potassium (NPK) Dose – 30:30:0 kg NPK /ha Source – Urea, DAP and 20:20:0	
(8.6) How much residues left in field after harvesting (tones/ha) -	
(8.7) Crop yield: Normal year : 21.9 q/ha (2011-12) Worst year : 20.4 q/ha	
(8.8) Any other -	

Pedon 10

1. Name of the farmer	Babarao D. Dhabare
2. Location and address	At post - Pevartha Ta. - Nagpur, Dist. -Nagpur
3. Soil type (textural class and depth).	108 cm
4. Current cropping system-	Intercropping Cotton + Tur (Kharif)
5. Change in cropping system during last 10 years	No
6. Type of farming	Rainfed
7. Methods of irrigation-	-
8. Crop wise information on the following aspects (for cotton) (8.1) Variety – Ankur 2534 bt (8.2) Sowing time - First week of July Area - 3 acre	
(8.3) Organic manure Not applied	
(8.4) Irrigation: No irrigation	
(8.5) Fertilizer - Nitrogen, Phosphorus and Potassium (NPK) Dose – 30:30:0 kg NPK /ha Source – Urea and DAP	
(8.6) How much residues left in field after harvesting (tones/ha) -	
(8.7) Crop yield: Normal year : 30.2 q/ha (2011-12) Worst year : 28.4 q/ha	
(8.8) Any other -	

Pedon 11

1. Name of the farmer	
2. Location and address	At post - Sawangi Ta. - Hingana, Dist. -Nagpur
3. Soil type (textural class and depth).	15 cm
4. Current cropping system-	Intercropping Cotton + Tur (Kharif)
5. Change in cropping system during last 10 years	No
6. Type of farming	Rainfed
7. Methods of irrigation-	-
8. Crop wise information on the following aspects (for cotton) (8.1) Variety – Paras Bt (8.2) Sowing time - First week of July Area - 3 acre	
(8.3) Organic manure Name - FYM Quantity applied - 3-4 ton (in alternate year) Time of application - Before sowing Method of application - Broadcasting	
(8.4) Irrigation: No irrigation	
(8.5) Fertilizer - Nitrogen, Phosphorus and Potassium (NPK) Dose – 30:30:0 kg NPK /ha Source – Urea, DAP and SSP	
(8.6) How much residues left in field after harvesting (tones/ha) -	
(8.7) Crop yield: Normal year : 12.1 q/ha (2011-12) Worst year : 9.7 q/ha	
(8.8) Any other -	

Pedon 12

1. Name of the farmer	Kashikar Mahadevrao Gawande
2. Location and address	At post - Shiva Ta. - Nagpur, Dist. -Nagpur
3. Soil type (textural class and depth).	150+ cm
4. Current cropping system-	Intercropping Cotton + Tur (Kharif) Gram (Rabi)
5. Change in cropping system during last 10 years	No
6. Type of farming	Rainfed
7. Methods of irrigation-	-
8. Crop wise information on the following aspects (for cotton) (8.1) Variety – Bunny Bt (NCS 5) (8.2) Sowing time - Last week of June Area - 6 acre	
(8.3) Organic manure Name - FYM Quantity applied - 5-6 ton (in alternate year) Time of application - Before sowing Method of application - Broadcasting	
(8.4) Irrigation: No irrigation	
(8.5) Fertilizer - Nitrogen, Phosphorus and Potassium (NPK) Dose – 30:30:0 kg NPK /ha Source – Urea, DAP and 20:20:0	
(8.6) How much residues left in field after harvesting (tones/ha) -	
(8.7) Crop yield: Normal year : 36.8 q/ha (2011-12) Worst year : 29.8 q/ha	
(8.8) Any other -	

