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Report no. 32

Chemical Characterization of Selected Benchmark Spots for C Sequestration in the Semi-Arid Tropics, India

International Crops Research Institute for the Semi-Arid Tropics

Central Research Institute for Dryland Agriculture (CRIDA)
National Bureau of Soil Survey & Land Use Planning (NBSS&LUP)
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Abstract

Soil organic carbon (SOC) plays an important role as a source of plant nutrients and in maintaining the soil integrity. Any land use management that increases SOC by removing CO_2 from the atmosphere by storing it in the soil, is termed as carbon sequestration. This study was conducted to learn about the role of various agricultural practices on soil nutrient dynamics and its relationship with SOC in various land use systems of semi-arid tropics (SAT). The study area covered 28 SAT benchmark spots, 21 out of which were on black soils and 7 on red soils, covering areas of 15.29 m ha and 6.34 m ha, respectively. Soils were sampled from the benchmark sites/pedons during

2000–03 and processed for chemical analysis. It was observed that irrespective of bioclimatic zones, land use under horticultural and agricultural systems in general, and paddy systems in particular, had maximum content of organic carbon and total N. The soil parameter viz. clay fraction also influenced the total N and total P, and hence organic carbon in black and red soils showed significant positive correlation with total N and P. Results indicated that perennials could sequester carbon better when compared to annual crops. The nutrient stocks and soil organic C and N ratio (carbon/nitrogen C:N), and carbon/phosphorus (C:P) were computed in addition to SOC for the purpose of identifying the maintained soil quality. It was observed that the C:N ratio varied from 16:1 to 22:1 under different zones and it was highest under semi-arid (moist) zones in black soils. Similarly C:P ratio of soils under various bioclimatic zones revealed that it was highest under sub-humid (moist), followed by arid zone and lowest under semi-arid zones. The C:N ratio of studied soils under various systems was wider than commonly accepted values reported for other tropical soils. The mean total N content of black soils was 0.042% and in case of red soils it was 0.052%, which corresponds to a minimum threshold level of 0.063% and 0.078% for black and red soils, respectively. Thus within the defined range of C:N ratios, those soils having SOC content of above values was considered along with minimum threshold values of total nitrogen stocks (Mg ha^{-1}) to arrive at the better systems. The minimum values of TN stocks was calculated with the established equation and the values for the corresponding levels of SOC was found to be 1.95 Mg ha^{-1} for black soils and 2.30 Mg ha^{-1} for red soils (both the soils types having an average bulk density of 1.5 Mg m^{-3}). Thus the soil total N stocks of systems that were found above the minimum threshold values are considered as better production systems.

The nutrient stocks and nutrient ratio in addition to soil organic carbon was used as the main criteria to develop the soil C:N index. The index varied between 0.27 and 0.87 with an average of 0.57 under the various systems spread over different bioclimatic zones and soil types. The variation of soil C:N index in different soil types showed that, the fertility status of red soils in terms of SOC and soil nutrient stocks in majority of the pedons was higher as compared to black soils. The variation in the soil C: N index due to bioclimatic zones in black and red soils, showed that semi-arid (moist) zone in black soils had the highest soil C: N index while the lowest was observed in sub-humid (moist) zone. As the MAR decreased from 1200 mm to 850 mm, the index increased from 0.30 to 0.38. Thus among the zones, the semi-arid moist was found to sequester more carbon. The variation in soil C:N index in different land use based systems such as horticultural (0.50) and forest systems (0.40) had better C:N index as compared to agricultural system in black soils. In red soils, forest system (0.76) had better C:N index as compared to agricultural system dominated by annual crops. Another significant observation was that permanent fallow land also had the potential to sequester carbon based on the magnitude of soil C:N index. The variation in the soil C:N index with the three major crop based systems studied showed that cereal based cropping systems sequester more carbon as compared to cotton and soybean based systems and can be promoted.

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Abbreviations

A	Arid
AESR	Agroecological subregions
Al	Aluminium
AS	Agricultural System
Avail. S	Available Sulphur
Avail. P	Available Phosphorus
BBF	Broad Bed and Furrow
BM	Benchmark
BMP	Best Management Practices
C	Carbon
C:N ratio	Carbon Nitrogen ratio
C:P	Carbon Phosphorus ratio
CO+PP	Cotton+Pigeonpea
CA+PP	Castor+Pigeonpea
CO	Cotton
CO/GG+PP	Cotton/Greengram+Pigeonpea
CO/GN-W	Cotton/Groundnut-Wheat
CO+BG	Cotton+Blackgram
CO+PP/S	Cotton+Pigeonpea/Sorghum
CO+PP/SB-G	Cotton+Pigeonpea/Soybean-Gram
CO-B	Cotton-Bajra
CO-B/LS	Cotton-Bajra/Linseed
CO_2	Carbon dioxide
CP	Chickpea
CO-PP/S	Cotton-Pigeonpea/Sorghum
CO-W/CP	Cotton-Wheat/Chickpea
FAO	Food and Agriculture Organization
F-CP	Fallow-Chickpea
Fe	Iron
Fig.	Figure
FM	Farmers' Management
FiM	Finger Millet
FiM/PP/RG/GN	Finger Millet/Pigeonpea/Redgram/Groundnut
GN-CO	Groundnut-Cotton
HG-V	Horsegram-Vegetables

HM	High Management
HS	Horticultural System
IFAD	International Fund for Agricultural Development
IPCC	Inter-govermental Panel on Climate Change
KS	Karnataka state
LM	Low Management
MA-MU	Maize-Mustard
MAR	Mean Annual Rainfall
Mha	Million hectares
MM/SP	Minor Millet/Sweet Potato
MN	Mineral Nitrogen
MS	Maharashtra state
$NaHCO_3$	Sodium Bicarbonate
NBSS & LUP	National Bureau of Soil Survey and Land Use Planning
NPK	Nitrogen Phosphorus Potassium
OC	Organic Carbon
OM	Organic Matter
P28	Pedon 28
PF	Permanent Fallow
P-P	Paddy-Paddy
P-W	Paddy-Wheat
P/W/MA	Paddy/Wheat/Maize
S-CA	Sorghum-Castor
S/PP+GG	Sorghum/Pigeonpea+Green gram
S/SF/CO	Sorghum/Sunflower/Cotton
SB+PP	Soybean+Pigeonpea
S+PP/BG-CP	Sorghum+Pigeonpea/Blackgram-Chickpea
SA (D)	Semi-Arid (Dry)
SA (M)	Semi-Arid (Moist)
SAT	Semi-Arid Tropics
SB/P-W	Soybean/Paddy-Wheat
SB-PP	Soybean-Pigeonpea
SB-G	Soybean-Gram
SB-G/W	Soybean-Gram/Wheat
SB-W	Soybean-Wheat
SB-W	Soybean-Wheat

SC/J-W/G	Sugarcane/Jowar-Wheat/Gram
SC-SB/W/CP	Sugarcane- Soybean/Wheat/Chickpea
SH (D)	Sub-Humid (Dry)
SH (M)	Sub-Humid (Moist)
SIC	Soil Inorganic Carbon
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
Soil CNP ratio	Soil Carbon : Nitrogen : Phosphorus
SB-W	Soybean-Wheat
T	Teak
TC	Total Carbon
Tg	Terragram ($Tg=10^{12}g$)
TM	Traditional Management
TN	Total Nitrogen
TP	Total Phosphorus
WL	Wasteland

Contents

Introduction

Carbon dioxide (CO_2) is one of the principal greenhouse gases and its concentration in the atmosphere has been steadily increasing. The atmospheric CO_2 increased by about 32% from 280 μmol/mol during 1850 to about 370 μmol/mol by 2000. The atmospheric CO_2 is currently increasing at the rate of 0.5% per year (3.4 Pg C/year) (Swift 2001). Predictions suggest a continued increase in the concentration of $CO_{2,}$ and it is estimated that emissions will reach 26 Gt C y^{-1} by 2100 from the 7.4 Gt C y^{-1} in 1997. The international scientific community and several international bodies such as Inter-govermental Panel on Climate Change (IPCC), Food and Agriculture Organization (FAO) and International Fund for Agricultural Development (IFAD) have also expressed serious concern about increased atmospheric carbon dioxide. This increase in CO_2 concentration is expected to have serious environmental consequences, and global warming is one such major consequence. Agriculture being sensitive to climatic change is expected to experience a variety of problems due to changes in environment. The increase in CO_2 is mainly of anthropogenic origin, since this period coincides with the massive and ongoing expansion of the human population and widespread adoption of technologies involving increased reliance on energy from fossil fuels. After the Kyoto Protocol on Global Climate Change in December 1997, a global effort to reduce and/or maintain the CO_2 concentration was initiated, which includes reducing emissions and increasing sequestration of carbon (C). This protocol became legally binding on its 128 parties on 16 February 2005. While being a signatory to the Protocol, India does not have emission reduction targets. But it could play a significant role in offseting the emission of carbon by way of terrestrial carbon sequestration due to the presence of diverse climate, soil type and vegetation. The potential of agricultural soils was duly recognized in article 3.4 of the Kyoto Protocol and the idea of sequestering C in soils as soil organic carbon (SOC) was considered as a possible means of reducing atmospheric CO_2.

Soil organic carbon is essential to maintain a good physical condition and to absorb, retain and supply water and nutrients to crops. Since all the SOC is derived from CO_2 in the atmosphere, any land-use management that increases SOC will remove CO_2 from the atmosphere, thereby making the soil act as a sink for CO_2. This process of removing CO_2 from the atmosphere and storing it in the soil is termed carbon sequestration. Every pound of SOC represents 3.7 pounds of CO_2 removed from the atmosphere (McConkey, Internet source). It has been estimated that 20% or more of targeted emission reduction could be met by agricultural carbon sequestration (Report of Consortium for Agricultural Soil Mitigation of Greenhouse Gases (CASMGS).

It is estimated that most of the 97 mha land under rainfed agriculture in India is situated in the semi-arid tropics (SAT). It is characterized by sub-humid, semi-arid and arid bioclimatic zones with Alfisols, Entisols, Vertisols and associated soils which dominate these areas (Virmani et al. 1991). These soils are generally coarse – textured, highly degraded with low retentive capacity, have multiple nutrient deficiencies, and are especially low in organic carbon and nitrogen (Singh et al. 2004), and are prone to further degradation due to inappropriate soil, water and nutrient management practices currently followed. Carbon sequestration, therefore, assumes a special significance in these areas by serving the dual purpose of reducing the atmospheric concentration and increasing the soil organic carbon. In this regard, forests and agricultural crops rank the foremost and are estimated to contribute a net removal of about 2 Gt C y^{-1} from the atmosphere. The projected potential to increase this net removal of carbon from atmosphere through adoption of improved management strategies is 5–10 Gt C y^{-1}. A number of long-term experiments show a direct relatioship between C input rates and soil C levels. To realize this potential, an understanding of the impact of various agricultural practices on C sequestration in the cultivated lands and development of new strategies to shift land from low-carbon sequestration use to high-carbon sequestration is required. Adoption of best management practices (BMPs), such as no-till practices, application of amendments, fertilization and irrigation, which enhance production, also influence carbon cycle in the soil. By making modest changes to existing farming practices, plants and soils can be used much more efficiently to remove CO_2 from the atmosphere. The role of application of amendments, fertilizers and other practices aimed at improved carbon sequestration should also be understood. This project aims at identifying farming systems that can reduce CO_2 concentration in the atmosphere and increase the stocks of soil organic carbon and other nutrients while maintaining or increasing the systems, overall productivity in SAT, India.

Nutrient resources vary across landscapes, hence understanding the processes that lead to its spatial variation has become the focal point of ecological research (Benning and Seastedt 1995). It also becomes necessary to identify richer lands having better vegetative cover to improve the soil organic carbon content and land productivity. Many studies have identified soil nutrient availability to be an important factor controlling net primary productivity (Pastor and Post 1986, Seastedt et al. 1991). Therefore characterizing spatial variability and distribution of nutrients in soil profile in relation to site characteristics including climate, land-use, and other variables is critical for predicting rate of ecosystem processes (Schimel et al. 1991).

Parent material (Kosmas et al. 1993), climate and geological history are of major importance in affecting soil properties on regional and continental scales. The different processes of soil formation result in differences in soil properties which further affect the pattern of crop production, root and litter production, decomposition and soil-organic-matter scenario of a particular soil ecosystem, and further influence the local C and N processes. Soil physical properties such as clay content distribution with depth, sand content and pH, are shown to be highly correlated with landscape position (Ovalles and Collins 1986). Thus, the soil organic matter content also varies with slope position, which is again related with aggregate stability, clay content and horizon-thickness differences among the slope positions. However, land-use in terms of varied management levels may be a major factor influencing soil properties under different climatic zones.

Most of the important soil processes such as erosion, oxidation, mineralization and leaching, etc, occur in different magnitudes due to adoption of various land-use and soil-management practices (Lepsch et al. 1994; Fu et al. 1999; Hontoria et al. 1999) and alter the redistribution of nutrients among the surface and sub-surface horizons of soil profiles. In forest and fallow land-use systems, the type of vegetative cover is a factor influencing the soil organic carbon content (Grigal and Ohmann 1992). Management and choice of crop have a profound impact on the soil and play an important role in enhancing soil quality. Legume-based systems helped in maintaining or enhancing SOC conent (Wani et al. 1994 & 2003). Hence, land-use and type of vegetation must be taken into account when relating soil nutrients with environmental conditions (Hontoria et al. 1999) and in characterizing soil nutrients/soil nutrient stocks. Ratios like carbon to nitrogen is a primary indication of how chemical composition will influence decomposition because chemical composition of residue also controls decay rate. Vegetation and cropping practices influence both in terms of quality and quantity of carbon inputs and have an impact on both the accumulation and duration of organic matter stored in soil and ultimately on nutrient stocks.

Farmers of SAT India are economically weak, and hence poor adoption of technologies by the farming community continues to remain a perplexing issue even with technology packages with apparent benefits. Hence, a wide gap exists between the potential yield on the research farms, yield levels in verification trials, and the actual yield under real farm conditions (CRIDA 1997). Hence farmers select crops and cropping systems based on their needs and other socioeconomic considerations. In recent years, large areas are being adopted for experimentation on crops and various cropping systems. These include conversion from perennial systems to annual systems, shifting from one crop to another and replacing a traditional variety with an improved one, all of which have a significant influence on the C cycle in the soil. Expansion of the area under groundnut cultivation in the drier areas of southern India and the area under soybean in central India are two such examples where major shifts in cropping system have taken place. Most of the studies have been in relation to characterizing soil nutrients and stocks in soils of semi-arid tropical regions but not pertaining to land-use and varied management-level practices. This report with the following objectives explains the impact of various agricultural practices and management levels, as adopted by the experimental stations and farmers, on soil nutrient dynamics and its relationship with SOC in various land-uses of SAT, with the aim of identifying potential carbon-sequestering production systems in the SAT benchmark sites:

- To assess the dynamics of soil nutrients and stocks including total nitrogen (TN), total phosphorus (TP), mineral N (MN), available phosphorus (AP) and available sulphur S (AS), and their relationships with soil organic carbon, and the effects of land-use and management levels in different bioclimatic zone of black and red soils.
- To identify production system(s) that sequester higher organic carbon in the soil and sustain the system.

Materials and Methods

2.1 Site Description

The study area consisted of vast plains of sub-humid, semi-arid and arid ecosystems, which covered Karkeli (MP) in east to Semla (Gujarat) in the west and from Jhalipura (Rajasthan) in the north to Kovilpatti (Tamil Nadu) in the southern India. It covered 28 benchmark (BM) spots, 21 out of which were on black soils and 7 on red soils. The BM spots included 52 pedon sites with 40 on black soils and 12 on red soils, with a total area of 21.9 mha out of a potential identified area of 150.9 mha identified for the purpose of carbon sequestration in dry sub-humid agro-eco subregions (AESRs 9.1, 9.2, 10.1, 10.2, 10.3, 10.4) (Velayutham et al. 1999). The study area of black soils was distributed in five different bioclimatic zones, viz., SH (m), SH (d), SA (m), SA (d) and arid, while red soils were distributed in three different bioclimatic zones, namely, SH (m), SA (m), SA (d) (Bhattacharyya et al. 2006a).

The above area was distinguished in terms of bioclimatic systems in view of variations in mean annual rainfall (MAR) in this vast area and grouped as under:

Sub-humid (moist) SH (m): > 1100 mm
Sub-humid (dry) SH (d): 1100 mm to 1000 mm
Semi-arid (moist) SA (m): 1000 mm to 850 mm
Semi-arid (dry) SA (d): 850 mm to 550 mm
Arid: < 550 mm

The soil types of the experimental sites included those of black and red soils from established benchmark spots and represented two major soil orders – Vertisols and their Vertic intergrades (black soils) covering an area of 15.29 mha and Alfisols and associated groups (red soils) covering an area of 6.34 mha. The distribution of benchmark spots in black and red soils is shown in Figure 2.2.

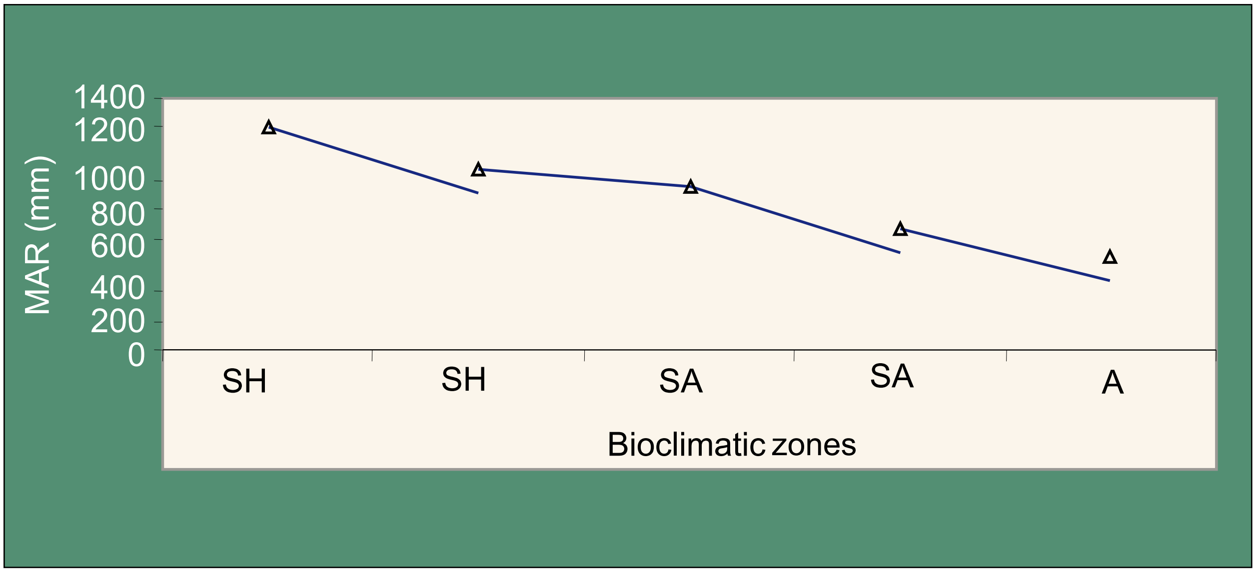


Figure 2.1. The variation in rainfall in different bioclimatic systems.

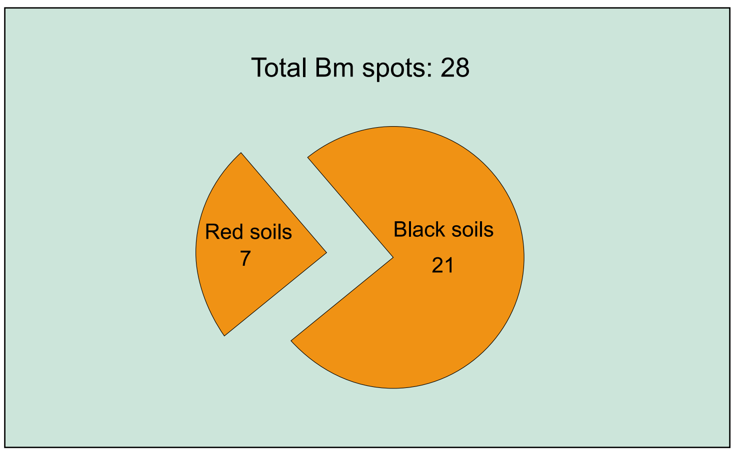


Figure 2.2. Distribution of BM spots among soil types.

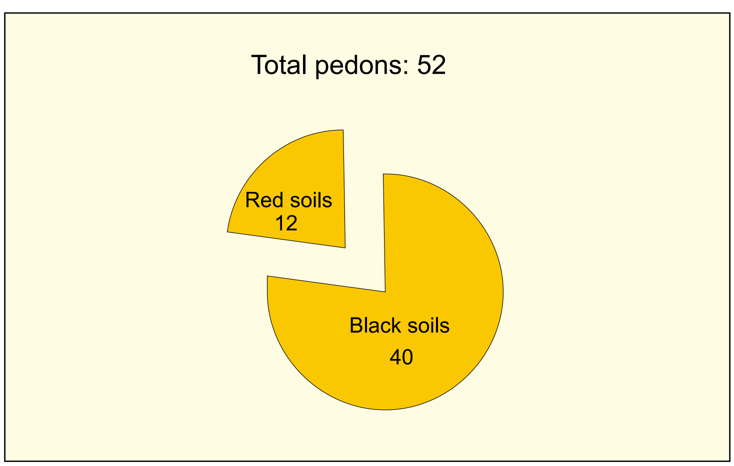


Figure 2.3. Distribution of Pedons among soil types.

The source of information on the soil series from different benchmark spots taken up for the study is presented in the table below.

Table 2.1. Sources of soil series information from different benchmark spots.

Sl. No.	Benchmark spots	Sources
1.	Teligi (KS)	Barde et al. (1974)
2.	Sarol (MP)	Murthy et al. (1982); Lal et al. (1994); Tamgadge et al. (1999)
3.	Asra (MS)	Anonymous (1999c)
4.	Vijaypura (KS)	Murthy et al. (1982); Lal et al. (1994)
5.	Sokhda (Guj.)	Sharma et al. (1988)
6.	Paral (MS)	Anonymous (1999c)
7.	Kheri (MP)	Murthy et al. (1982); Lal et al. (1994)
8.	Linga (MS)	Murthy et al. (1982); Lal et al. (1994)
9.	Kaukuntla (AP)	Anonymous (1999a)
10.	Jajapur (AP)	Anonymous (1999a)
11.	Semla (Guj.)	Lal et al. (1994); Sharma et al. (1988)
12.	Palathurai (TN)	Murthy et al. (1982); Lal et al. (1994)
13.	Kalwan (MS)	Challa et al. (1999)
14.	Patancheru (AP)	Murthy and Swindale (1990); Lal et al. (1994); Kalbande and Reddy (1972)
15.	Kasireddipalli (AP)	Lal et al. (1994)
16.	Nimone (MS)	Lal et al. (1994)
17.	Panjri (MS)	Anonymous (1990)
18.	Jhalipura (Raj.)	Anonymous (1999b); Shyampura et al. (2002)
19.	Nabibagh (MP)	NBSS & LUP Staff (1994)
20.	Nipani (AP)	BM spots visited and name proposed by NBSS & LUP (RNPS-25) group
21.	Pangidi (AP)	BM spots visited and name proposed by NBSS & LUP (RNPS-25) group
22.	Dadarghugri (MP)	Bhattacharyya and Pal (1998); Sehgal et al. (1994)
23.	Boripani (MS)	Naitam (2001); Naitam and Bhattacharyya (2004)
24.	Bhatumbra (KS)	Shiva Prasad et al. (1998)
25.	Konheri (MS)	NBSS & LUP Staff (1995)
26.	Kovilpatti (TN)	Kalbande et al. (1992)
27.	Hayatnagar (AP)	BM spots visited and name proposed by NBSS & LUP (RNPS-25) group
28.	Karkeli (MP)	BM spots visited and name proposed by NBSS & LUP (RNPS-25) group

Source: (Bhattacharyya et al. 2006b).

2.2 Description of Land-use/Farming Systems

Soil-and crop-management practices were examined in five broad land-use systems, viz., agricultural, horticultural, forest, fallow and wasteland. Maximum numbers of BM spots and pedons are distributed in agricultural systems (Figures 2.4 and 2.5).

Under each BM spot, pedons are identified based on different management levels. Accordingly, the following broad levels of management are taken into consideration, viz., high-management (HM), low management (LM) and farmers'-management (FM, which is mostly low-management practice) in order to study the nutrient dynamics in soils as influenced by varied fertility levels. Thus the basis for the classification of a practice as HM or LM is presented in Table 2.2.

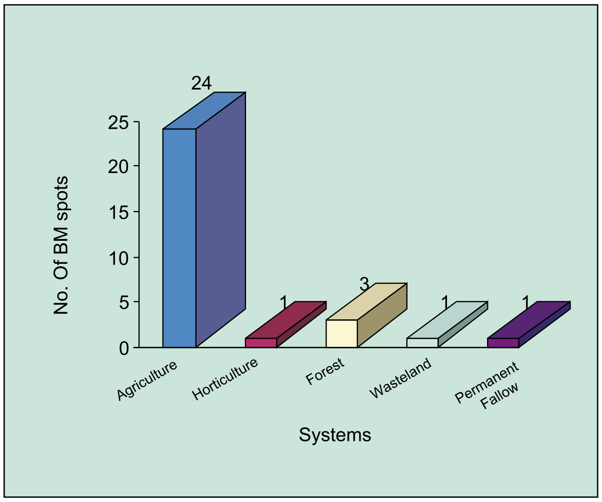


Figure 2.4. Distribution of BM spots in different land-use systems.

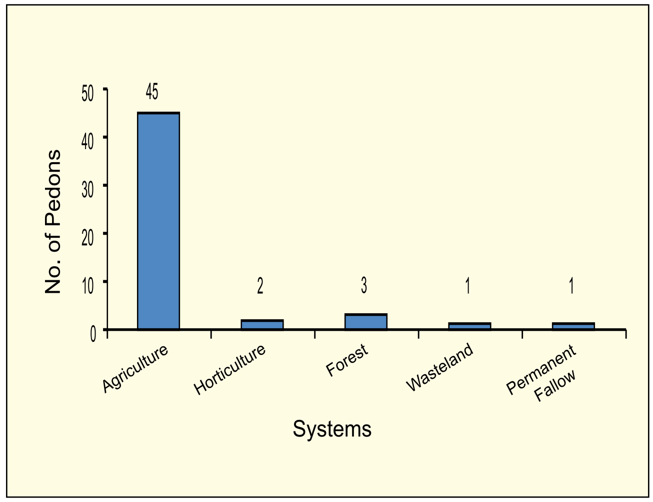


Figure 2.5. Distribution of pedons in different land-use systems.

Table 2.2. Definition of various management practices.

Sl. no.	High-management (HM)	Low management (LM)
1.	High dose of NPK (which are location specific)	Low dose of NPK
2.	Regular application of manures	Manures rarely applied
3.	Intercropping with legumes	Sole crop
4.	Incorporation of residues	Removal of residues and biomass
5.	Soil moisture conservation (ridge furrows, bunding, BBF)	Nil

Three major cropping patterns were selected within the agricultural system based on the dominant crop, namely cotton, soybean and cereals. The various cropping systems under each of the above crops and their respective pedon numbers are given in Tables 2.3 to 2.5.

Table 2.3. Distribution of pedons under cotton-based cropping systems.

Cropping pattern	Pedons
Cotton	P4
Cotton + Pigeonpea	P48, P49
Cotton + Pigeonpea/Soybean-Chickpea	P12
Cotton + Pigeonpea/Sorghum	P13, P14
Cotton/Green gram + Pigeonpea	P10
Cotton + Blackgram	P21
Cotton/Groundnut-Wheat	P29
Cotton-Pearl millet	P30
Cotton-Pearl millet/Linseed	P31
Cotton-Wheat/Chickpea	P51

Table 2.4. Distribution of pedons under soybean-based cropping system.

Cropping pattern	Pedons
Soybean/Paddy-Wheat	P28
Soybean-Wheat	P5, P6, P7, P8, P32
Soybean	P50
Soybean-Chickpea	P9
Soybean-Chickpea/Wheat	P2
Soybean + Pigeonpea	P11, P39

Table 2.5. Distribution of pedons under cereal-based cropping systems.

	Cropping pattern	Pedons
Paddy	Paddy-Wheat	P27, P33
	Paddy-Paddy	P36, P44
Millets	Finger millet	P16
	Finger millet/Pigeonpea/Red gram/Groundnut	P17
	Finger millet	P18
	Minor millet/Sweet potato	P26
Sorghum	Sorghum + Pigeonpea/Black gram-Chickpea	P42
	Sorghum/Pigeonpea+Green gram	P35
	Sorghum/Sunflower/Cotton	P19
	Sorghum-Castor	P37, P38
Maize	Maize/Mustard	P23

2.3 Soil Sampling

Fields were sampled from the above-mentioned benchmark sites/pedons during the year 2000–03 and they were air dried. The air-dried samples were then ground to pass through a 2 mm sieve and stored in sealed plastic containers at room temperature. A sub-sample of soil, milled to pass through a 200 mm screen was used for total P measurement. Analysis of samples for total N (TN), mineral N (MN) and available S (AS) were carried out with the 2 mm-sieved soil samples using the procedures mentioned in Table 2.6.

Table 2.6. References for various nutrient analyses undertaken in the study.

Sl. no.	Soil nutrient	Method	Reference
1.	Total Nitrogen	Combustion method	Bremner and Mulvaney 1992
2.	Total Phosphorus	Microwave digestion method	Watanabe and Olsen 1965
3.	Mineral N	Incubation method	Mulvaney 1996
4.	Available P	Extraction with 0.5 M $NaHCO_3$	Olsen et al. 1954
5.	Available S*	Extraction with 0.15% $CaCl_2$ (red soils) and Mono calcium phosphate containing 500 ppm P (black soils) and estimation by turbidity method	Williams and Steinbergs 1959

*Selection of suitable extractant to estimate available S in different soil types is influenced by many factors, the most important being clay content, pH, exchangeable cations and calcium carbonate content. Absorption of sulphate by soils is negligible above 6.5 pH and increases with decreasing pH below this value (Williams and Steinbergs 1962). Considering the high clay and calcium carbonate content of black soils, mono calcium phosphate containing 500 ppm P was selected as the best extractant.

2.4 Computation of Soil Nutrient Stocks

The mass of soil nutrients stored in an equivalent soil mass was calculated using available data of bulk density at various soil depths. Accordingly, the first step was to calculate the mass of nutrient per unit area in each soil layer, which was arrived by multiplying (total or available) nutrient content (g/g), bulk density (Mg/m^3) and thickness of horizon (m) for individual soil profiles with different thicknes: 0–30, 0–50, 0–100 and 0–150 cm. In the second step, the total/available nutrient content calculated by the previous step is multiplied by the area (ha) of the soil unit and distributed in different agro - ecological subregions (AESR) (Velayutham et al. 1999 and 2000). The source of information for the areal extent of the soil series in each benchmark spot is shown in the table (Table 2.7). The total and available nutrient content was calculated in terms of Tg (Tg = 10^{12} g).

2.5 Statistical Analysis

Linear correlation was used to test the significant difference between measured variants/variables (SPSS 1998).

Table 2.7. Areal extent of soil series and their references.

Sl. no.	Benchmark spots	Area ('000 ha)	Sources
1.	Teligi	659.0	Shiva Prasad et al.(1998)
2.	Sarol	721.0	Tamgadge et al. (1996)
3.	Asra	1866.4	Challa et al. (1995)
4.	Vijaypura	841.0	Shiva Prasad et al.(1998)
5.	Sokhda	604.4	Sharma et al. (1994)
6.	Paral	1185.0	Challa et al. (1995)
7.	Kheri	464.1	Tamgadge et al. (1996)
8.	Linga	129.5	Sehgal et al. (1994)
9.	Kaukuntla	755.6	Reddy et al. (1996)
10.	Jajapur	1153.3	Reddy et al. (1996)
11.	Semla	485.7	Sharma et al. (1994)
12.	Palathurai	345.1	Natarajan et al. (1997)
13.	Kalwan	618.9	Challa et al. (1995)
14.	Patancheru	1462.5	Reddy et al. (1996)
15.	Kasireddipalli	391.3	Reddy et al. (1996)
16.	Nimone	46.5	Sehgal et al. (1994)
17.	Panjri	635.9	Tamgadge et al. (1995)
18.	Jhalipura	1153.7	Shyampura et al. (1996)
19.	Nabibagh	486.9	Tamgadge et al. (1996)
20.	Nipani	533.4	Reddy et al. (1996)
21.	Pangidi	1021.1	Reddy et al. (1996)
22.	Dadarghugri	138.66	Tamgadge et al. (1996)
23.	Boripani	1673.1	Annonymous (1990), Challa et al. (1995)
24.	Bhatumbra	259.9	Shiva Prasad et al. (1998)
25.	Konheri	362.5	Challa et al. (1995)
26.	Kovilpatti	1291.5	Natarajan et al. (1997)
27.	Hayatnagar	1725.2	Reddy et al. (1996)
28.	Karkeli	623.9	Tamgadge et al. (1996)

(Source: (Bhattacharyya et al. 2006b).

Results and Discussion

3.1 Total Nitrogen

Total nitrogen measures the amount of nitrogen bound to soil mineral particles and organic matter. Total N is generally much higher than the amount of nitrogen available for plant uptake. Depending upon the parent material and extent of weathering, the total N (%) content of soil all over the world ranges from 0.015 to 0.137. Variation in total N is mainly due to different rock types and organic matter.

3.1.1 Variation of total N in different bioclimatic zones

3.1.1.1 Black soils

The variation in the content of total N in 0–30 cm depth in different zones is presented in Figure 3.1.1. The content ranged from 364 mg kg^{-1} in the arid zone to 564 mg kg^{-1} in the sub-humid (dry) zone. The lower content of total N in SH (M) could be attributed to the low level of management practised in this zone and to some extent due to high rainfall which results in considerable loss of SOM by way of leaching. With decrease in rainfall, the total N content decrease from the sub-humid (dry) to the arid zone. The total N content was found varying with varying levels of organic carbon and total P content (Figures 3.1.2 and 3.1.3). The lowest content of total N was observed in the arid zone where the content of total P as well as organic carbon was also found to be minimum. However, highest content of total P and organic carbon was observed in the semi-arid (moist) zone. Significant positive correlation of total N with organic carbon was observed in 0–30 cm, and the total N content was also highly and significantly correlated with clay, fine clay, mineral N and organic carbon at higher depths, which is illustrated in Figures 3.1.4 to 3.1.8. At 0–150 cm also, positive and significant relationships between total N and clay (r=0.43*), fine clay (r=0.54**) and SOC (r=0.54**) were observed.

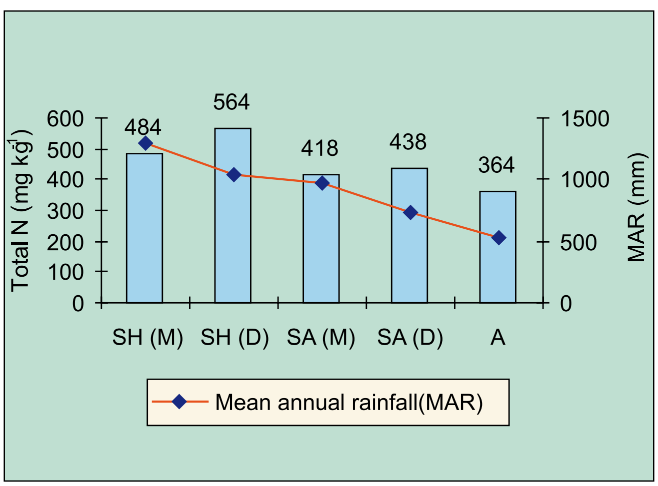


Figure 3.1.1. Total nitrogen content of black soils at 0 – 30 cm depth in different bioclimaic zones.

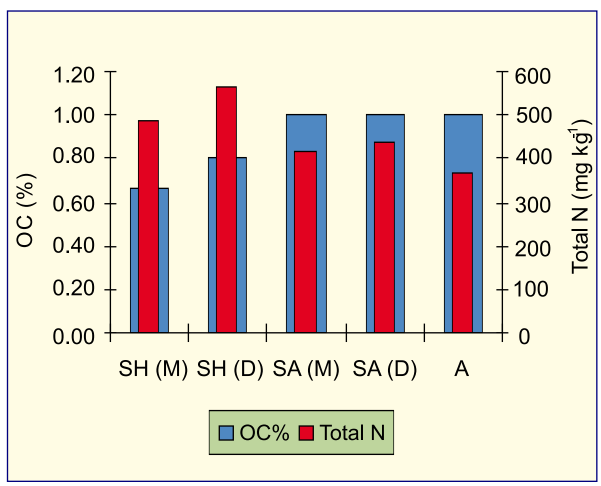


Figure 3.1.2. Status of total N in relation to OC content of soils at 0 – 30 cm depth in different bioclimatic zones in black soils.

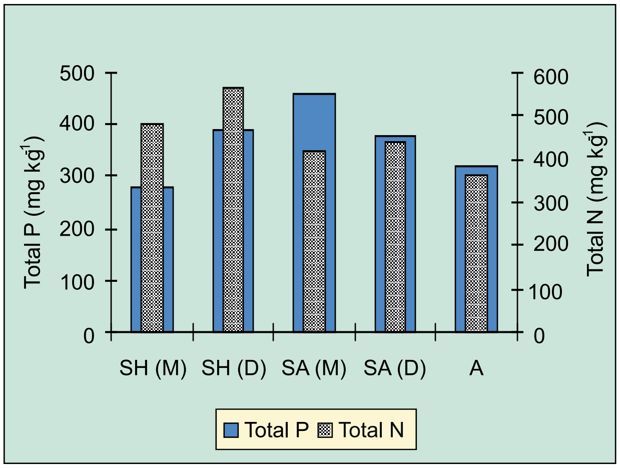


Figure 3.1.3. Status of total N in relation to total P content of soils at 0–30 cm depth in different bioclimatic zones in black soils.

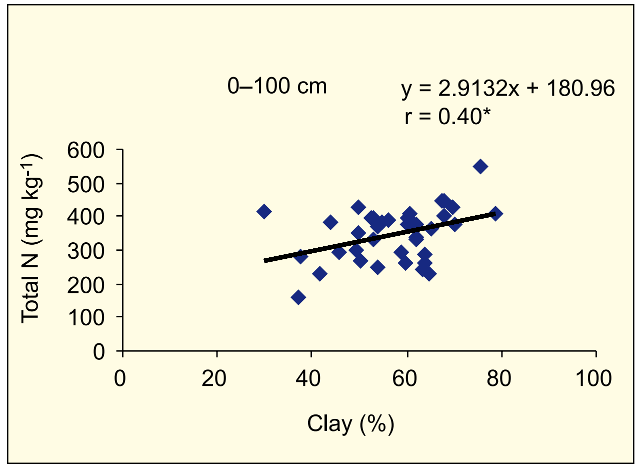


Fig. 3.1.4

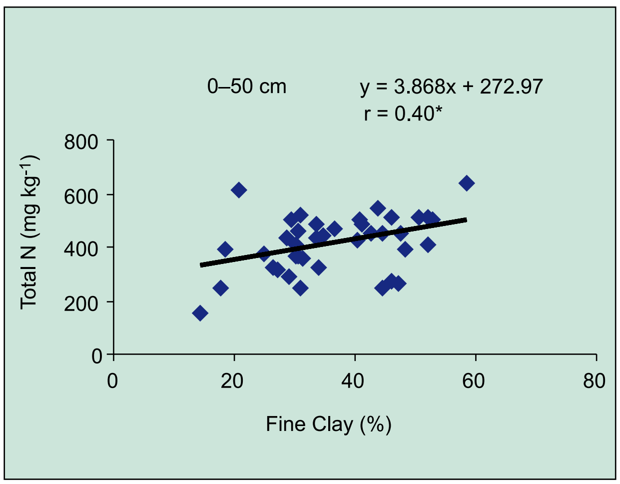


Fig. 3.1.5

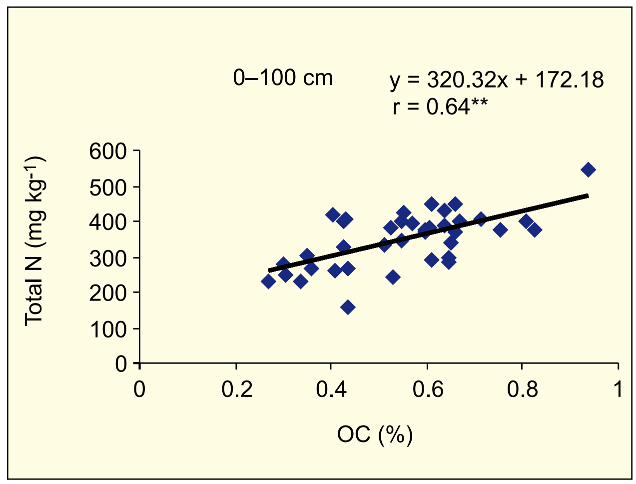


Fig. 3.1.6

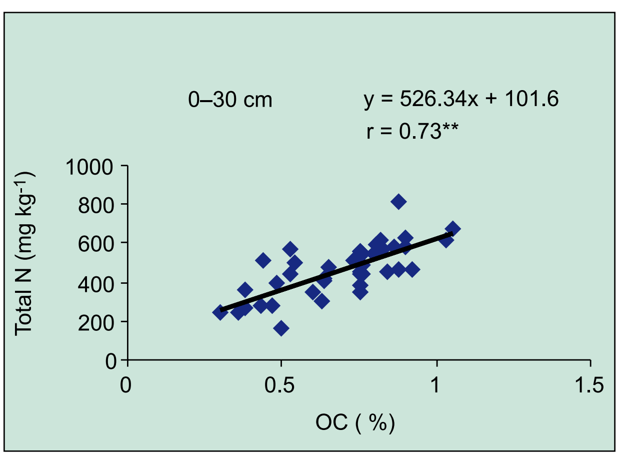


Fig. 3.1.7

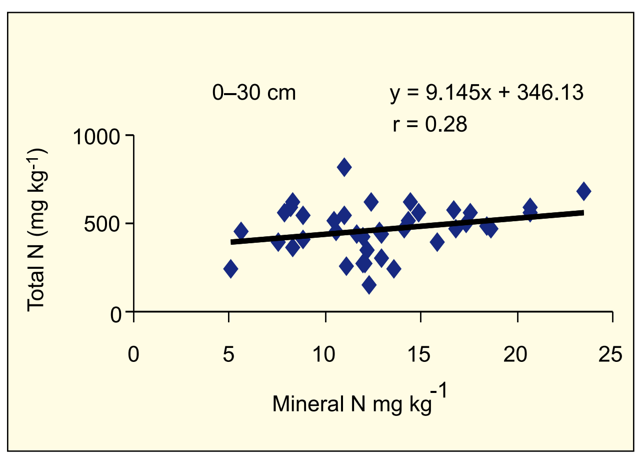
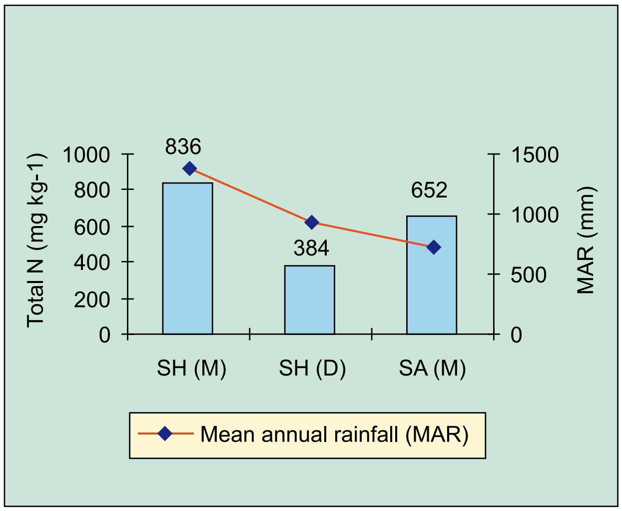


Fig. 3.1.8

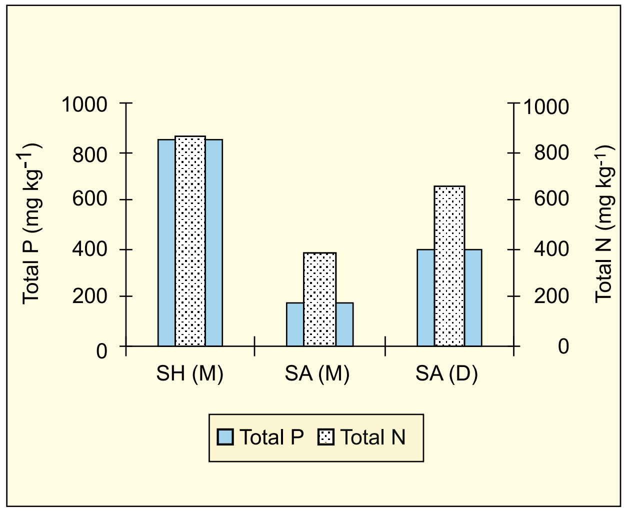
Figures 3.1.4 to 3.1.8. Relationship of various soil parameters with total N in black soils at different depths.

3.1.1.2 Red soils

The variation in the content of total N in different bioclimatic zones in the red soils is shown in Figure 3.1.9. The content at 0–30 cm depth was maximum under sub-humid (moist) and minimum under semi-arid (moist) zone. This difference in total N can be attributed to the decreasing rainfall coupled with other soil parameters. Accordingly, the total N content proportionately increased with total P and organic carbon content (Figures 3.1.10 and 3.1.11). The total N content was positively correlated with soil organic carbon, total P and clay fractions irrespective of the bioclimatic zones (Figures 3.1.12 to 3.1.15). The high content of total N in SH (M) was due to high content of N in the soils of Dadarghugri.



Figures 3.1.9. Total nitrogen content of red soils in different bioclimaic zones.



Figures 3.1.10. Status of total N in relation to total P content of soils at 0–30 cm depth in different bioclimatic zones in red soils.

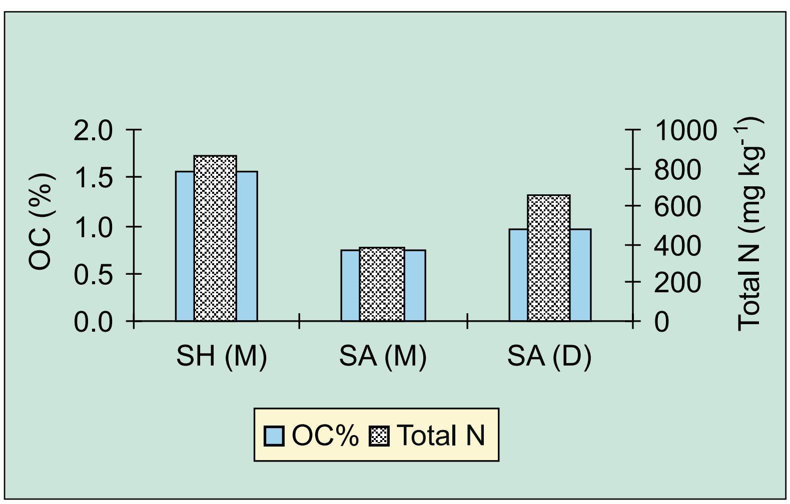
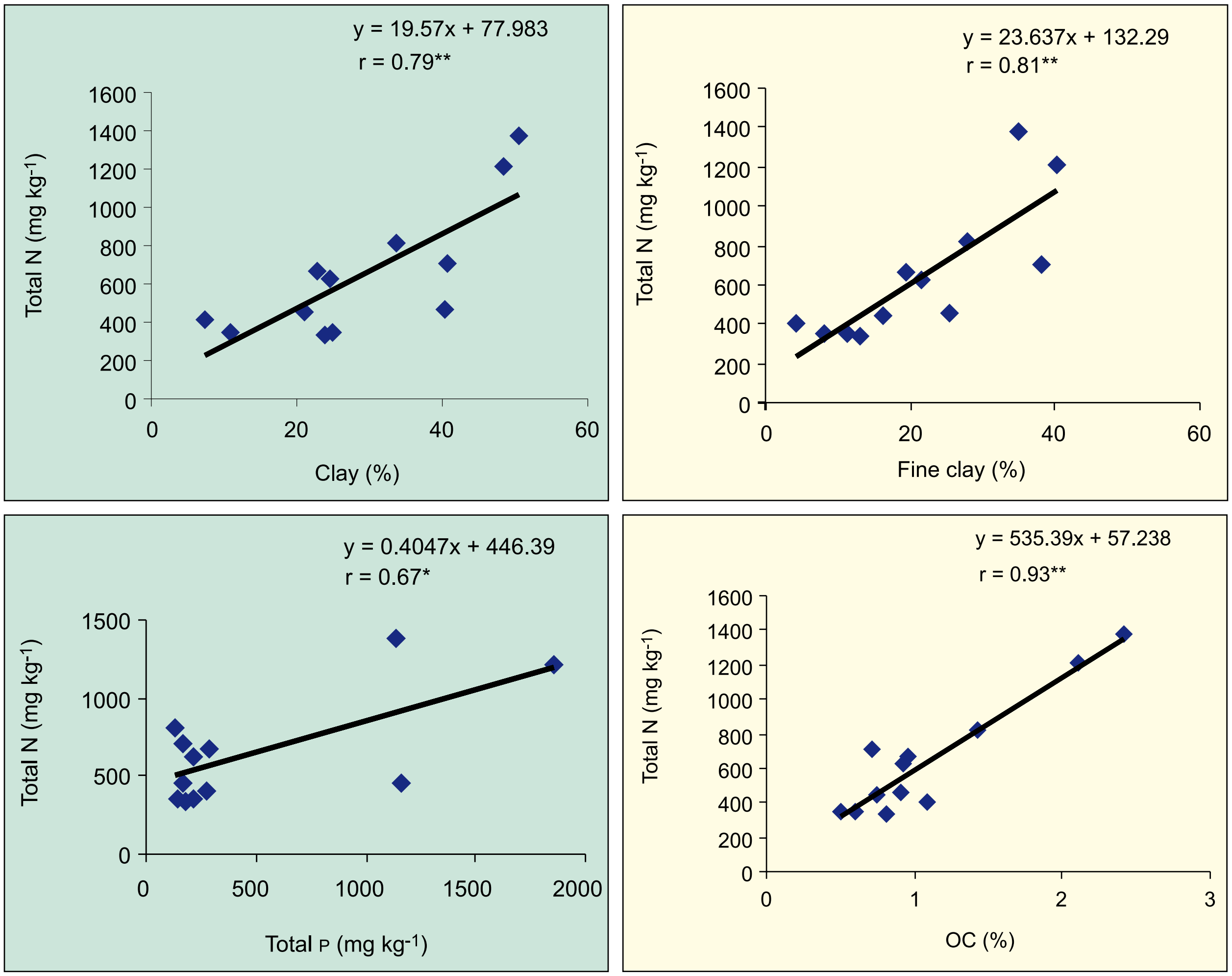


Figure 3.1.11. Status of total N in relation to organic carbon content of soils at 0–30 cm depth in different bioclimatic zones in red soils.



Figures 3.1.12 to 3.1.15. Relationships of various soil parameters with total N in red soils at 0–30 cm depth.

3.1.2 Variation of total N in different benchmark locations

Black Soils

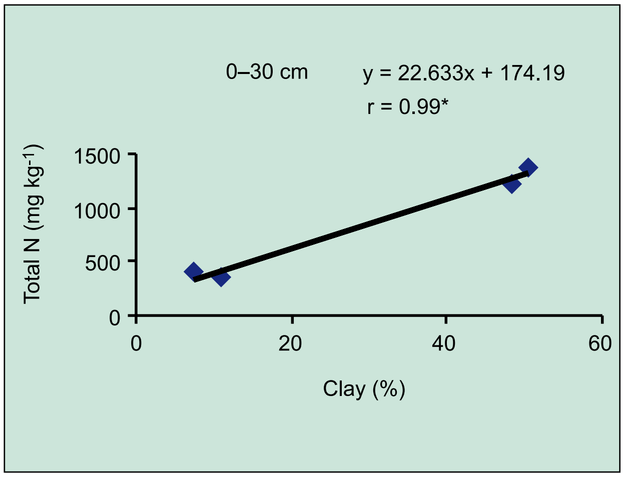
3.1.2.1 Sub-humid (moist)

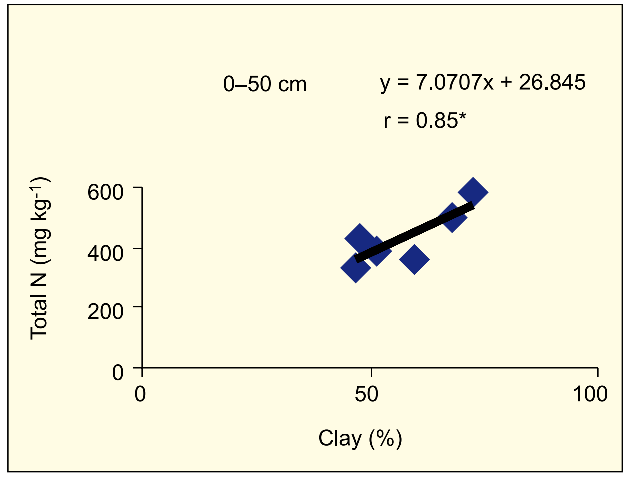
The variation in total N content in different benchmark locations under sub-humid (moist) zone is presented in Table 3.1.1.

Table 3.1.1. Profile distribution of total N concentration in black soils in various benchmark locations under sub-humid (moist) zone.

				Total N (mg kg^{-1})			
				Soil depth (cm)			
Sl. no.	Series	System	P. no.	0–30	0–50	0–100	0–150
1.	Kheri	Agriculture (HM) Rice/Wheat/Maize	P27	565	488	407	385
2.	Kheri	Agriculture (FM) Soybean-Wheat	P28	404	370	348	290
3.	Boripani	Reserve forest teak	P15	588	548	375	280
4.	Nabibagh	Agriculture (HM) Soybean-Wheat	P5	451	406	370	369
5.	Nabibagh	Agriculture (FM) Soybean-Wheat, Gram	P6	476	433	397	381
6.	Panjri	Agriculture (HM) Cotton	P4	421	389	335	301

The content of total N varied between 404 mg kg^{-1} in Kheri series (P28) to 588 mg kg^{-1} in Boripani series (P15). The low content of total N in soils of Kheri, Nabibagh and Panjri series was due to the cultivation with high-exhaustive crops such as soybean, wheat, etc, together with low SOC content. The variation of P15 (which was 46% more over P28) could be attributed to the land-use system, ie, forest over agriculture system where an increased organic carbon and clay might have an effect on total N. Figures. 3.1.16 and 3.1.17 show the significant correlation of total N and clay at 0–30 and 0–50 cm depths wherein at greater depth, total N was also positively correlated with total P (Figure 3.1.18). The content of total N was found to decrease with depth which again highlights the influence of SOC in the distribution of total N.





Figures 3.1.16 to 3.1.17. Relationships of total N with different soil parameters at various depths in black soils under sub-humid (moist) zone.

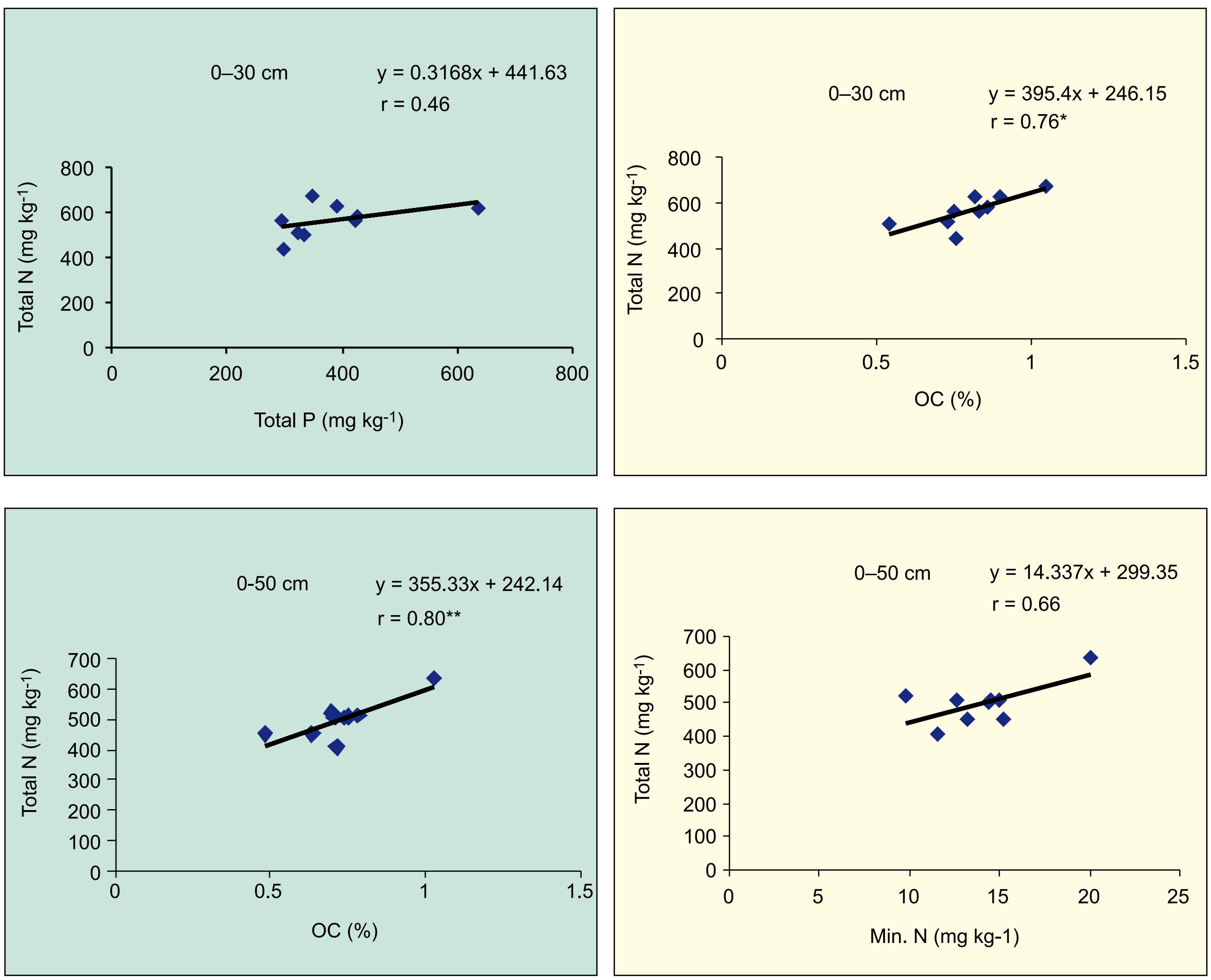
3.1.2.2 Sub-humid (dry)

The extent of variation in total N content in different benchmark location under sub-humid (dry) is presented in Table 3.1.2.

Table 3.1.2 Profile distribution of total N concentration in black soils in various benchmark locations under sub-humid (dry) zone.

				Total N (mg kg^{-1})			
				Soil depth (cm)			
Sl. no.	Series	System	P. no.	0–30	0–50	0–100	0–150
1.	Nipani	Agriculture (FM) Cotton+Pigeonpea and alternative Sorghum and Maize	P48	621	523	425	372
2.	Pangidi	Agriculture (FM) Soybean+Pigeonpea	P49	675	636	547	483
3.	Pangidi	Agriculture (ITDA) Soybean	P50	623	508	332	273
4.	Sarol	Agriculture (HM) Soybean-Wheat	P7	502	452	401	368
5.	Sarol	Agriculture (FM) Soybean-Wheat	P8	437	409	367	330
6.	Sarol	Agriculture (HM) Soybean-Gram	P9	511	452	393	361
7.	Linga	Horticulture (HM) Orange	P1	563	509	429	383
8.	Linga	Horticulture (LM) Orange	P3	582	512	449	406
9.	Linga	Agriculture (FM) Soybean-Gram/Wheat	P2	564	505	447	394

The total N content in black soils at 0–30 cm depth varied between 437 mg kg^{-1} in Sarol series (P8) and 675 mg kg^{-1} in Pangidi series (P49). This 54% increase of total N in P49 over P8 could be attributed to the difference in the organic carbon content in these two series and presence of pigeonpea crop in p49: 1.05% for P49 and 0.76% for P8. The high content of total N in soils of Nipani series could be due to the effect of parent material such as limestone, which is rich in carbon. The cultivation of crops in soils of Pangidi is rainfed and the area was found to be fallow/forest for a very long time, which might have resulted in high SOC content. Similarly, a high content of total N in P50 is seen where the Integrated Tribal Development Agency (ITDA) is practising high-management practices for the cultivation of soybean. The difference in total N content of soils in P8 over P7 and P9 could also be due to high-management levels of crop production. However, there was no marked difference in the total N content in soils of Linga series (P1 and P3). The soils of P2 were managed by farmers and recently cultivated with agricultural crops like soybean and wheat, where previously a horticultural system existed. That could be a reason for the high content of total nitrogen (TN) similar to that of P1 and P3. The positive relationship of various soil parameters with total N in this zone was evident from the higher depths as shown in figures 3.1.20 to 3.1.21.



Figures 3.1.18 to 3.1.21. Relationship of total N with different soil parameters at various depths in black soils under sub-humid (dry) zone.

3.1.2.3 Semi-arid (moist)

The variation in total N content in different benchmark locations under semi-arid (moist) zone is given in Table 3.1.3.

Table 3.1.3. Profile distribution of total N concentration in black soils in various benchmark locations under semi-arid (moist) zone.

				Total N (mg kg^{-1})			
				Soil depth (cm)			
Sl. no.	Series	System	P. no.	0–30	0–50	0–100	0–150
1.	Bhatumbra	Agriculture (FM) Sorghum+Pigeonpea/ Black gram-Chickpea	P42	465	430	377	342
2.	Asra	Agriculture (FM) Cotton-Green gram-Pigeonpea intercropping Cotton/Pigeonpea	P10	347	319	286	264
3.	Asra	Agriculture (FM) Soybean-Pigeonpea intercropping Soy/PP	P11	388	360	338	327
4.	Asra	Agriculture (HM) Soybean-Gram-Cotton-Pigeonpea	P12	470	425	375	348

The total N content in 0–30 cm depth varied from 347 mg kg^{-1} in soils of Asra series (P10) to 470 mg kg^{-1} in soils of P12 in Asra series. The difference in total N within the same benchmark location was due to the differences in organic carbon and clay content. The practice of soil cultivation with legumes in Bhatumbra series and addition of legumes like berseem in the soils of Asra series could be the major reasons for the high content of total N. There was a decrease in soil total N content with increasing depth in all the soil series.

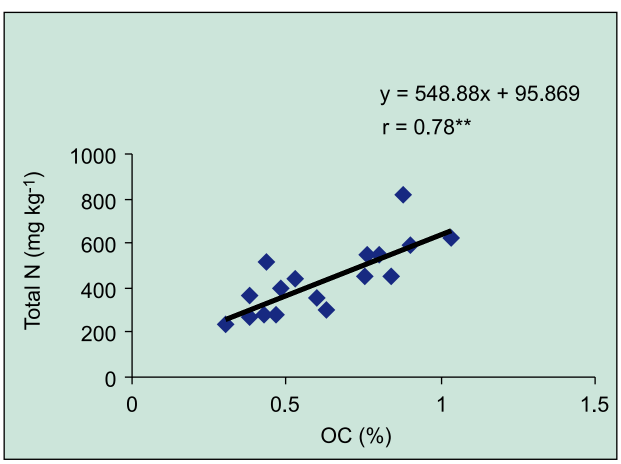
3.1.2.4 Semi-arid (Dry)

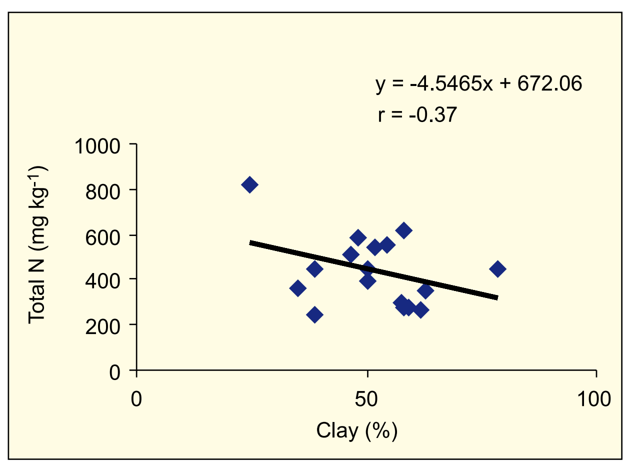
The variation in total N content in different BM locations in semi-arid (dry) zone is presented in Table 3.1.4.

The amount of total N in 0–30 cm soil depth varied from 241 mg kg^{-1} in soils of Konheri series (P45) to 816 mg kg^{-1} in soils of Jajapur series (P36). High content of total N was found in soils of Jhalipura where paddy and wheat crops were harvested and in paddy systems of Jajapur and Teligi as well as in Kalwan series where high-fertilized crops like maize and sugarcane were cultivated. Analysis of soil TN content of the above soil series with the remaining systems in this zone again highlights the role of management levels and cultivation of legumes such as pigenpea in influencing this soil parameter. The low content of TN in soils of Konheri series (P45) as compared to P46 could be attributed to the presence of coarse textured sandy layer in this area, which result in low soil SOC (0.30 % as against 0.84 % in case of P46) and hence low soil TN content. The soils of Kasireddypalli series in P39 were also found to contain higher TN due to cultivation of legumes with high levels of management. The high content of total N content in paddy soils of Jhalipura and Teligi could be due to higher application of manures, nitrogenous fertilizers and root biomass of paddy which also added considerable amount of organic carbon. This was further evident from positive relationship observed between total N and organic carbon in this zone (Figure 3.1.22). However, the clay content of this zone failed to establish any positive relationship with total N content (Figure 3.1.23).

Table 3.1.4. Profile distribution of total N in black soils in various benchmark locations under semi-arid (dry) zone.

Sl. no.	Series	System	P. no.	Total N (mg kg^{-1}) Soil depth (cm) 0–30	0–50	0–100	0–150
1.	Jhalipura	Agriculture (FM) Soybean-Wheat	P32	511	431	325	290
2.	Jhalipura	Agriculture (FM II) Paddy-Wheat	P33	443	374	266	218
3.	Paral	Agriculture (LM) Cotton-Sorghum-Pigeonpea	P13	298	290	291	289
4.	Paral	Agriculture (HM) Cotton-Pigeonpea-Sorghum	P14	354	325	240	220
5.	Jajapur	Agriculture (FM I) Sorghum-Pigeonpea-Greengram	P35	364	327	279	250
6.	Jajapur	Agriculture (FM II) Paddy-Paddy	P36	816	613	418	321
7.	Kasireddipalli	Agriculture (HM) Soybean-Pigeonpea intercropping	P39	544	460	384	344
8.	Kasireddipalli	Agriculture (TM) Fallow-Bengal gram	P40	396	364	330	302
9.	Konheri	Agriculture (FM) Pigeonpea/ Sunflower Fallow-Sorghum	P45	241	246	230	223
10.	Konheri	Agriculture (LM) Fallow-Sorghum	P46	451	445	406	309
11.	Kalwan	Agriculture (FM) Maize-Sugarcane/ Onion/Wheat	P47	587	499	380	290
12.	Kovilpatti	Agriculture (original) Sorghum	P19	265	247	230	215
13.	Kovilpatti	Wasteland	P20	280	260	264	249
14.	Kovilpatti	Agriculture (HM) Cotton	P21	279	275	261	236
15.	Semla	Agriculture (FM) Groundnut/Cotton	P29	447	390	296	262
16.	Teligi	Agriculture (LM) Paddy-Paddy	P43	622	504	398	357
17.	Teligi	Agriculture (HM) Paddy-Paddy	P44	551	467	374	331





Figures 3.1.22 to 3.1.23. Relationship of total N with other parameters at 0–30 cm depth in black soils in semi-arid (dry) zone.

3.1.2.5 Arid

The variation in total N content in different benchmark locations under arid zone is given in Table 3.1.5.

Table 3.1.5. Profile distribution of total N concentration in black soils in various benchmark locations under arid zone.

Sl. no.	Series	System	P. no.	Total N (mg kg^{-1}) Soil depth (cm) 0–30	0–50	0–100	0–150
1.	Sokhda	Agriculture (FM I) Cotton/Pearl millet	P30	248	250	251	203
2.	Sokhda	Agriculture (FM II) Cotton-Pearl millet/Linseed	P31	158	153	158	152
3.	Nimone	Agriculture (HM) Cotton-Wheat/ Chickpea (irrigated)	P51	488	452	402	359
4.	Nimone	Agriculture (FM) Sugarcane-Soybean/ Wheat/ Chickpea	P52	560	487	390	329

The variation in total N content ranged from 158 mg kg^{-1} in soils of Sokhda series (P31) to 560 mg kg^{-1} in Nimone series (P52). The soils of P31 are moderately deep with inherently low content of TN. This is further coupled with presence of deep-rooted crops like cotton along with low levels of soil management, which resulted in low content of TN in these soils. The soils of Nimone series are well managed with nutrient inputs along with irrigation, which has resulted in high content of total N. The soils of P52 were found to have certain soil physical properties such as low hydraulic conductivity and were also cultivated with high-nutrient input crops like sugarcane, soybean, etc, which might have resulted in high soil TN.

Red soils

3.1.2.6 Sub-humid (moist)

The variation in total N content of red soils in different benchmark locations of sub-humid (moist) zone is given in Table 3.1.6.

Table 3.1.6. Profile distribution of total N concentration in red soils at various benchmark locations of sub-humid (moist) zone.

Sl. no.	Series	System	P. no.	Total N (mg kg^{-1}) Soil depth (cm) 0–30	0–50	0–100	0–150
1.	Dadarghugri	Agriculture (LM) Maize-Mustard (Pigeonpea)	P23	1214	1130	1098	1067
2.	Dadarghugri	Forest system teak	P24	1374	1032	802	717
3.	Karkeli	Forest system sal	P25	407	332	286	282
4.	Karkeli	Agriculture (LM) Sweet potato/ Minor millet (kodo)	P26	348	389	410	388

The total N content varied between 348 mg kg^{-1} in soils of Karkeli series (P26) under agriculture system and 1374 mg kg^{-1} in soils of Dadarghugri series (P24) under forest system. The organic carbon content in these two systems also showed a considerable difference (0.60% for P26 as against 2.42% for P24). The high content of total N in Dadarghugri series was primarily due to addition of lot of OM through litters and decomposition of leaves of forest sp. The soils are acidic and are characterized by the absence of lime nodules. The cultivation of maize and mustard was taken up in these cleared forest lands but cultivation was taken up not in an exhaustive manner. The crop yield was also generally low and the addition of inputs was also minimal. The soils of adjacent forests with teak system (P24) have high TN which could be due to parent material and the vegetation of teak, which is a dicotyledonous legume with low C:N ratio (19.6) and high N content. The low content of TN in soils of Karkeli series was due to parent material being poor in nitrogen content as well as presence of monocotyledonous forest species like sal and low-exhaustive crops like sweet potato and millets.

3.1.2.7 Semi-arid (moist)

The variation in total N content of red soils in different benchmark locations under semi-arid (moist) zone is given in Table 3.1.7.

Table 3.1.7. Profile distribution of total N in red soils in various benchmark locations under semi-arid (moist) zone.

				Total N (mg kg^{-1})			
				Soil depth (cm)			
Sl. no.	Series	System	P. no.	0–30	0–50	0–100	0–150
1.	Vijayapura	Agriculture (FM) Finger millet	P16	461	277	399	356
2.	Vijayapura	Agriculture (original) Pulses	P17	353	333	293	254
3.	Vijayapura	Agriculture (HM) Finger millet	P18	337	307	270	142

The total N content varied between 337 mg kg^{-1} in Vijayapura series (P18) under high-management and 461 mg kg^{-1} under P16 in farmers' management system. The difference in total N content varied due to variations in organic carbon content. The farmers' management in soils of Vijayapura series (P16) are characterized by high levels of inputs as compared to soils of experimental stations (P18), and diverse cropping system that resulted in high SOC and soil TN content as compared to other series. The content of TN decreased with depth in all the soil series in this zone.

3.1.2.8 Semi-arid (dry)

The variation in total N content in different benchmark locations under semi-arid (dry) is given in Table 3.1.8.

Table 3.1.8 Profile distribution of total N concentration in red soils in various benchmark locations under semi-arid (dry) zone.

Sl. no.	Series	System	P. no.	Total N ($mg\ kg^{-1}$) Soil depth (cm) 0–30	0–50	0–100	0–150
1.	Hayatnagar	Agriculture (HM) Sorghum-Castor	P37	626	720	612	515
2.	Hayatnagar	Agriculture (LM) Sorghum-Castor	P38	666	661	506	366
3.	Patancheru	Fallow system Permanent fallow grassland	P41	816	773	609	778
4.	Kaukuntla	Agriculture (FM) Castor+Pigeonpea	P34	704	670	562	479
5.	Palathurai	Horticulture (original) Tomato	P22	448	424	364	356

The TN content at 0–30 cm depth varied between 448 $mg\ kg^{-1}$ in Palathurai series (P22) and 816 $mg\ kg^{-1}$ in Patancheru series (P41). The high content of TN in soils of P37 was due to adoption of high-management wherein sorghum residues along with considerable quantities of fertilizers were added. In the soils of P38, though an LM system with similar cropping pattern, the TN and SOC content was found to be higher than in P37, which could be due to the cultivation of above crops in this land-use system where there might have existed a land-use with higher content of SOC such as forest, grassland, etc. The organic carbon content of soils has considerable variation within this zone. The high content of TN in soils of Patancheru series could be attributed partly to the parent material, which was weathered granite and gneiss, and mostly due to the land-use which was a permanent closed grassland system with high activity of earthworms. The high content of TN in soils of Kaukuntla was partly due to soil association of black and red soils and due to addition of more biomass of castor crop.

3.1.3 Variation of total N under different land-use systems

The content of total N in black and red soils at 0–30 cm depth in different systems is given in Figures. 3.1.24 and 3.1.25, respectively. The total N content in black soils under wasteland was the lowest (280 $mg\ kg^{-1}$) where the system would not have received any fertilizers or organic matter. Soils under forest and horticulture systems were observed to contain maximum content of total N, which was followed by agriculture, where it was 459 $mg\ kg^{-1}$. The high content of total N in soils of forest system was due to the low C:N ratio observed. Management practices like fertilizer inputs might have resulted in high content of the total N in soils of horticulture system. Similarly, red soils under forest system had the highest content of total N that was closely followed by permanent grassland fallow, and it was lowest under agricultural systems (Figure 3.1.25).

3.2 Mineral Nitrogen

Mineral N refers to the amount of ammoniacal and nitrate nitrogen that is present in a soil at a given time. The reservoir of mineral N in the soil, particularly ammonium and nitrate is low-less than 50 mg kg^{-1} soil, and amounting to only a few kg ha^{-1}, in marked contrast to the enormous reservoir of organic nitrogen from which it is derived. The cropping systems and the weather conditions greatly influence the amount and distribution of mineral N in soil. Many experiments have shown that the importance

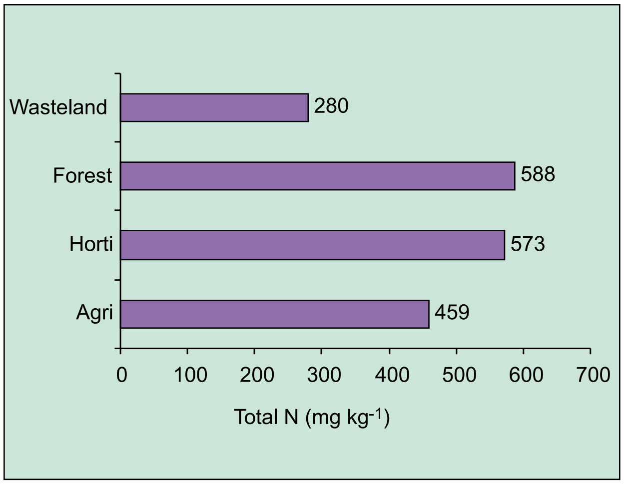


Figure 3.1.24. Total N content in black soils at 0–30 cm depth under different systems.

Figure 3.1.25. Total N content in red soils at 0–30 cm depth under different systems.

of mineral N and its estimation has resulted in savings of nitrogenous fertilizers. Estimation of mineral N in soil samples before cropping may indicate the potential N-supplying capacity of the soil. Mineral N closely correlates with the growth, nitrogen uptake and yield of the crops, indicating the need to consider mineral N when fertilizer recommendations are made. It can be expected that nitrogen fertilizers and addition of organic matter significantly increase the mineral N content of soils. Hence, an understanding of mineral N and its dynamics under various bioclimatic systems and management practices, where different levels of fertilizer nitrogen are used in different soil types of SAT India under various cropping systems, is important.

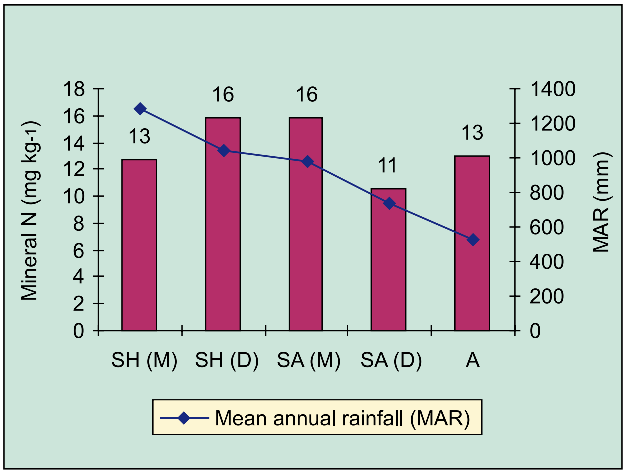
3.2.1 Variation of mineral N in different bioclimatic zones

3.2.1.1 Black soils

The distribution of mineral N at 0–30 cm depth in different bioclimatic zones is given in Figure 3.2.1. The content of mineral N was low in soils of sub-humid (moist) and maximum (16 mg kg^{-1}) in soils of sub-humid (dry) and semi-arid (moist), and least in semi-arid (dry) zone. The arid zone was found to have an MN content of 13 mg kg^{-1}. The difference in the variation with respect to above zones could be due to the differences in soil C:N ratio, soil organic carbon and clay content. Figures. 3.2.2, 3.2.3 and 3.2.4 show the positive and significant relationship of mineral N with organic carbon and various clay fractions at different soil depths.

3.2.1.2 Red soils

The distribution of mineral N concentration at 0–30 cm depth in different bioclimatic zones of red soils is given in Figure 3.2.5. As in case of black soils, the sub-humid (moist) and semi-arid (moist) had a higher content of mineral N as compared to semi-arid (dry). Like black soils, it could be seen that the mineral N content had a positive relationship with total P, organic carbon and clay in red soil. (Figures. 3.2.6 to 3.2.8).



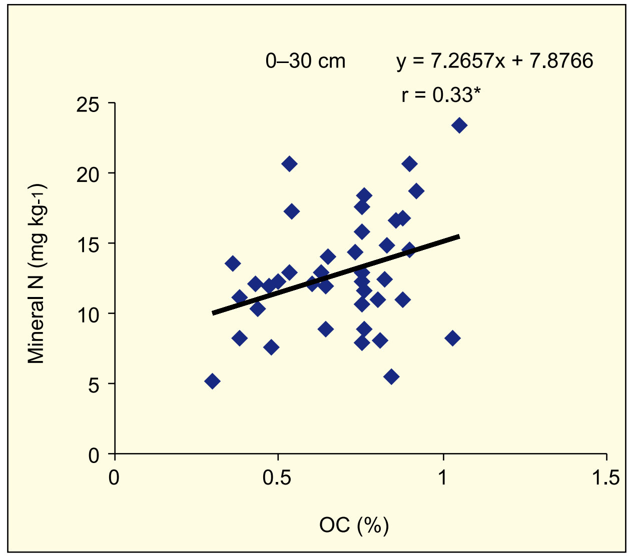
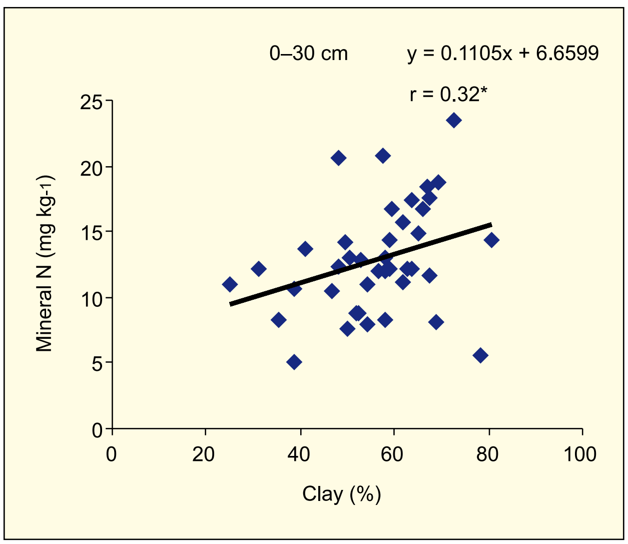
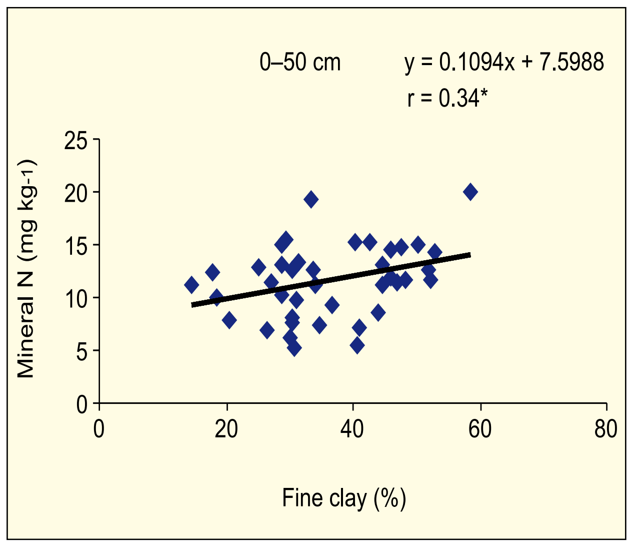
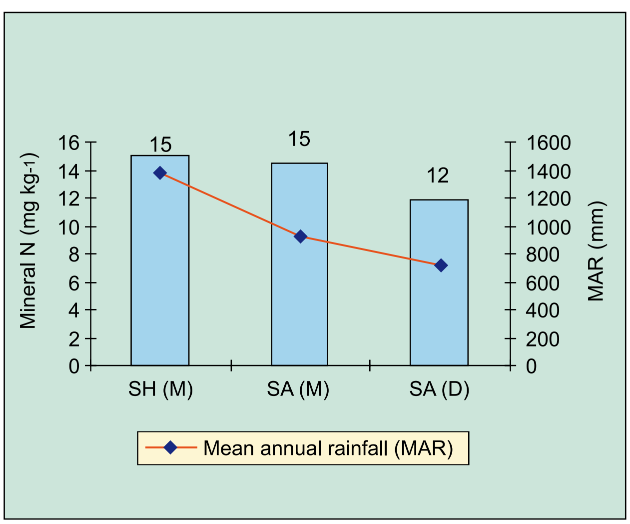


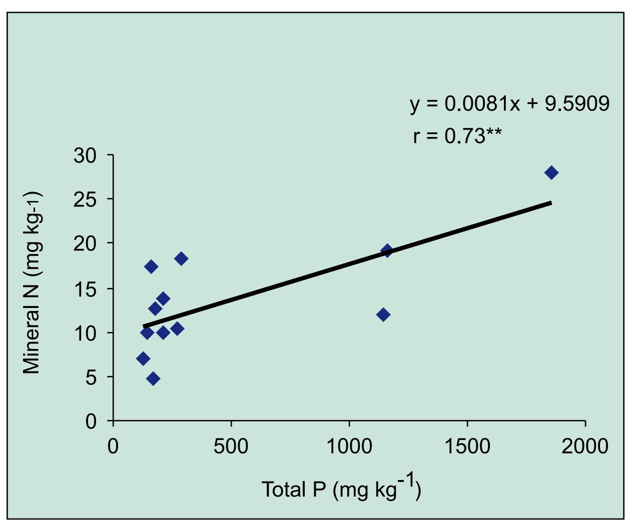
Figure 3.2.1. Mineral nitrogen content of black soils at 0–30 cm depth in different bioclimatic zones.

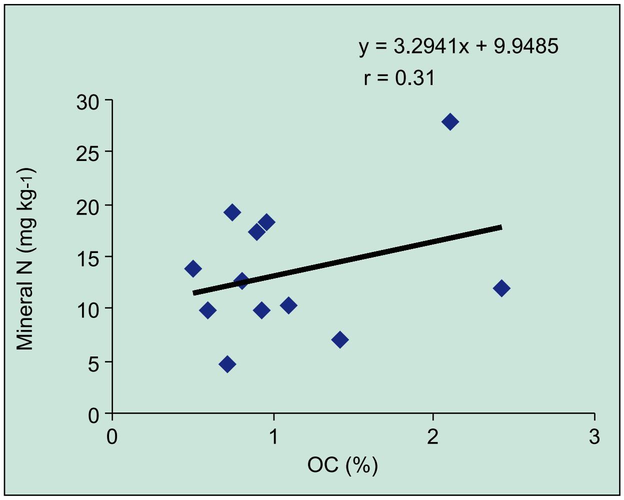


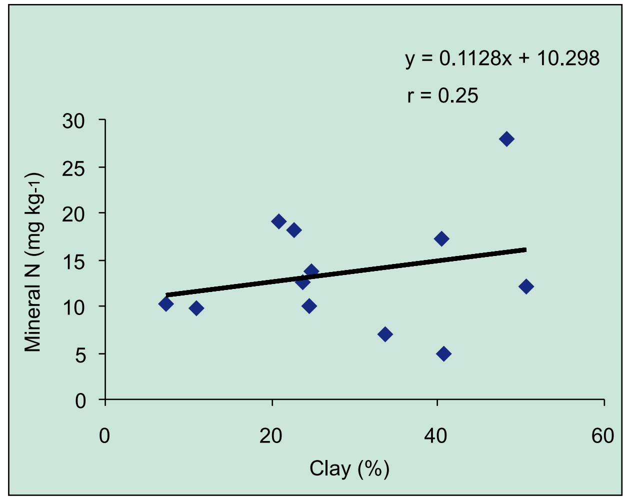


Figures 3.2.2 to 3.2.4. Relationship of various soil parameters with mineral N in black soils at different depths.









Figures 3.2.5 to 3.2.8. Relationship of various soil parameters with mineral N in red soils at 0–30 cm depth.

3.2.2 Variation in mineral N in different benchmark locations

Black Soils

3.2.2.1 Sub-humid (moist)

The mineral N concentration of black soils at various depths in sub-humid (moist) zone is given in Table 3.2.1.

Table 3.2.1. Profile distribution of mineral N concentration in black soils in various benchmark locations under sub-humid (moist) zone.

Sl. no.	Series	System	P. no.	Mineral N (mg kg^{-1}) 0–30	0–50	0–100	0–150
1.	Kheri	Agriculture (HM) Rice/Wheat/Maize	P27	21	19	16	15
2.	Kheri	Agriculture (FM) Soybean-Wheat	P28	9	8	7	6
3.	Boripani	Reserve forest teak	P15	8	9	8	8
4.	Nabibagh	Agriculture (HM) Soybean-Wheat	P5	13	13	14	14
5.	Nabibagh	Agriculture (FM) Soybean-Wheat, Bengal gram	P6	14	13	12	13
6.	Panjri	Agriculture (HM) CO	P4	12	12	11	11

The content of mineral N was found maximum at the surface and decreased with depth. The content varied from 8 mg kg^{-1} in the forest system of Boripani series (P15) to 21 mg kg^{-1} in the agriculture system of Kheri series (P27). The low content of mineral N in P15 may be due to the relatively high C:N ratio, which was found to be 15.2 as against 10.4 in P27. Thus, more mineral nitrogen is utilized for the microbial population to break up the organic substances through leaf litter and residue to maintain the C:N ratio during the above process, and hence low mineral N is found in these soils.

3.2.2.2 Sub-humid (dry)

The mineral N concentration of black soils at various depths in sub-humid (dry) zone is given in Table 3.2.2.

Table 3.2.2. Profile distribution of mineral N concentration in black soils in various benchmark spots under sub-humid (dry) zone.

Sl. no.	Series	System	P. no.	Mineral N (mg kg^{-1}) Soil depth (cm) 0–30	0–50	0–100	0–150
1.	Nipani	Agriculture (FM) Cotton+Pigeonpea and alternative Sorghum and Maize	P48	12	10	8	7
2.	Pangidi	Agriculture (FM) Soybean+Pigeonpea	P49	23	20	17	18
3.	Pangidi	Agriculture Soybean	P50	14	13	11	10
4.	Sarol	Agriculture (HM) Soybean-Wheat	P7	17	15	13	12
5.	Sarol	Agriculture (FM) Soybean-Wheat	P8	12	12	12	11
6.	Sarol	Agriculture (HM) Soybean-Bengal gram	P9	14	13	12	12
7.	Linga	Horticulture (HM) Orange	P1	18	15	12	12
8.	Linga	Horticulture (LM) Orange	P3	17	15	13	11
9.	Linga	Agriculture (FM) Soybean-Bengal gram/ Wheat	P2	15	14	14	13

The distribution of mineral N in 0–30 cm depth in sub-humid (dry) zone is given in Table 3.2.2. The content varied between 12 mg kg^{-1} in soil series of Nipani (P48), Sarol series (P8) and 23 mg kg^{-1} in Pangidi series (P49). The reasons for the low content of MN in soils of P8 could be due to fairly high C:N ratio of soil (19.3). The soils of P49 have been recently deforested and with the SOC being high (1.05%), and the C:N ratio of this soil tilting towards the mineralization range (17.3), the content of mineral N was found to be high. Similarly, the high-management soils were found to have a high content of MN as in case of P7, P1, etc.

3.2.2.3 Semi-arid (moist)

The mineral N concentration of black soils at various depths in semi-arid (moist) zone is given in Table 3.2.3.

Table 3.2.3. Profile distribution of mineral N concentration in black soils in various benchmark spots under semi-arid (moist) zone.

Sl. no.	Series	System	P. no.	Mineral N (mg kg^{-1}) Soil depth (cm) 0–30	0–50	0–100	0–150
1.	Bhatumbra	Agriculture (FM) Sorghum+ Pigeonpea/Black gram-Chickpea	P42	17	15	13	11
2.	Asra	Agriculture (FM) Cotton-Green gram-Pigeonpea intercropping Cotton/ Pigeonpea	P10	12	11	11	10
3.	Asra	Agriculture (FM) Soybean-Pigeonpea intercropping Soy/PP	P11	16	13	10	11
4.	Asra	Agriculture (HM) Soybean-Bengal gram-Cotton-Pigeonpea	P12	19	15	12	11

The content of mineral N in 0–30 cm depth varied between 12 mg kg^{-1} in Asra series (P10) to 19 mg kg^{-1} in P12 of the same series. The difference in the levels of management in the above series might have caused this variation as it was found that the soil of P10 was not under high-management. The high content of MN in soils of P12 could be attributed to high SOC content due to adoption of crop-rotation practices with sunhemp.

3.2.2.4 Semi-arid (dry)

The mineral N content of black soils at various depths in semi-arid (dry) zone is given in Table 3.2.4.

Table 3.2.4. Profile distribution of mineral N concentration in black soils in various benchmark spots under semi-arid (dry) zone.

				Mineral N (mg kg^{-1})			
				Soil depth (cm)			
Sl. no.	Series	System	P. no.	0–30	0–50	0–100	0–150
1.	Jhalipura	Agriculture (FM) Soybean-Wheat	P32	10	10	8	9
2.	Jhalipura	Agriculture (FM II) Paddy-Wheat	P33	13	13	12	10
3.	Paral	Agriculture (LM) Cotton-Sorghum-Pigeonpea	P13	13	13	13	10
4.	Paral	Agriculture (HM) Cotton-Pigeonpea-Sorghum	P14	12	11	10	9
5.	Jajapur	Agriculture (FM I) Sorghum-Pigeonpea-Green gram	P35	8	7	6	6
6.	Jajapur	Agriculture (FM II) Paddy-Paddy	P36	11	8	5	5
7.	Kasireddipalli	Agriculture (HM) Soybean-Pigeonpea intercropping	P39	9	8	9	8
8.	Kasireddipalli	Agriculture (TM) Fallow-Bengal gram	P40	8	6	4	4
9.	Konheri	Agriculture (FM) Pigeonpea/Sunflower Fallow-Sorghum	P45	5	5	5	6
10.	Konheri	Agriculture (LM) Fallow-Sorghum	P46	6	7	7	7
11.	Kalwan	Agriculture (FM) Maize-Sugarcane/Onion/Wheat	P47	21	16	12	9
12.	Kovilpatti	Agriculture (original) Sorghum	P19	11	11	10	10
13.	Kovilpatti	Wasteland	P20	12	11	11	11
14.	Kovilpatti	Agriculture (HM) Cotton	P21	12	12	11	11
15.	Semla	Agriculture (FM) Groundnut/Cotton	P29	11	10	9	12
16.	Teligi	Agriculture (LM) Paddy-Paddy	P43	8	5	6	6
17.	Teligi	Agriculture (HM) Paddy-Paddy	P44	11	9	7	5

The content of mineral N in semi-arid (dry) zone varied between 5 mg kg^{-1} in Konheri series (P45) and 21 mg kg^{-1} in Kalwan series (P47). The MN content of soils in all the other BM soils varied between 8–12 mg kg^{-1}. The reason for the higher content in P47 was due to management systems with high-fertilizer application for crops like sugarcane, wheat and vegetables. The soils of Konheri series had the lowest MN content of 5–6 mg kg^{-1} due to application of low rates of fertilizer and low levels of management. The content of soil MN was found to decrease with depth in all the soils in this zone.

3.2.2.5 Arid

The mineral N content and distribution in black soils at various depths and benchmark spots in arid zone is given in Table 3.2.5.

Table 3.2.5. Profile distribution of mineral N concentration in black soils in various benchmark spots under arid zone.

Sl. no.	Series	System	P. no.	Mineral N (mg kg^{-1}) Soil depth (cm)			
				0–30	0–50	0–100	0–150
1.	Sokhda	Agriculture (FM I) Cotton/Pearl millet	P30	14	12	12	11
2.	Sokhda	Agriculture (FM II) Cotton-Pearl millet/linseed	P31	12	11	10	10
3.	Nimone	Agriculture (HM) Cotton-Wheat/Chickpea (Irrigated)	P51	18	15	9	7
4.	Nimone	Agriculture (FM) Sugarcane-Soybean/Wheat/ Chickpea	P52	8	7	7	5

The MN content varied between 8–18 mg kg^{-1} in soils of Nimone series especially in the irrigated high-management system with optimum doses of fertilizer in case of P51, which was found to have high soil MN.

Red Soil

3.2.2.6 Sub-humid (moist)

The mineral N concentration of red soils at various depths in sub-humid (moist) zone is given in Table 3.2.6.

Table 3.2.6. Profile distribution of mineral N concentration in red soils in various benchmark locations under sub-humid (moist) zone.

Sl. no.	Series	System	P. no.	Mineral N (mg kg^{-1}) Soil depth (cm)			
				0–30	0–50	0–100	0–150
1.	Dadarghugri	Agriculture (LM) Maize-Mustard (Pigeonpea)	P23	28	23	19	18
2.	Dadarghugri	Forest system teak	P24	12	9	6	5
3.	Karkeli	Forest system sal	P25	10	9	6	5
4.	Karkeli	Agriculture (LM) Sweet potato/ Minor millet (kodo)	P26	10	9	6	5

The distribution of mineral N in various depths in sub-humid (moist) zone is given in Table 3.2.6. The mineral N content in 0–30 cm depth was higher in the soils of Dadarghugri and lower in Karkeli soils. High content of organic carbon and total N in the soils of P23 could be the reason for high content of mineral N compared to P26. However, the forest system of Dadarghugri had a comparatively low mineral N content (12 mg kg^{-1}), which could be due to the high C:N ratio of soils where the system was undisturbed and without any fertilizer input. The content of MN decreased with depth in all the soil series under this zone.

3.2.2.7 Semi-arid (moist)

The mineral N concentration of red soils at various depths in semi-arid (moist) zone is given in Table 3.2.7.

Table 3.2.7. Profile distribution of mineral N concentration in red soils in various benchmark spots under semi-arid (moist) zone

				Mineral N (mg kg^{-1})			
				Soil depth (cm)			
Sl. no.	Series	System	P. no.	0–30	0–50	0–100	0–150
1.	Vijayapura	Agriculture (FM) Finger millet	P16	17	14	13	13
2.	Vijayapura	Agriculture (original) Pulses	P17	14	13	13	13
3.	Vijayapura	Agriculture (HM) Finger millet	P18	13	12	10	9

The MN content among the soils of benchmark spot Vijayapura varied between 13 to 17 mg kg^{-1}. As mentioned earlier, the farmers' management in P16 was high-management where the input levels exceeded those recommended by the experimental station, which could be the reason for the high content of MN in those soils.

3.2.2.8 Semi-arid (dry)

The mineral N concentration of red soils at various depths in semi-arid (dry) zone is given in Table 3.2.8.

Table 3.2.8. Profile distribution of mineral N in red soils in various benchmark locations under semi-arid (dry) zone.

				Mineral N (mg kg^{-1})			
				Soil depth (cm)			
Sl. no.	Series	System	P. no.	0–30	0–50	0–100	0–150
1	Hayatnagar	Agriculture (HM) Sorghum-Castor	P37	10	9	7	6
2	Hayatnagar	Agriculture (LM) Sorghum-Castor	P38	18	16	13	12
3	Patancheru	Fallow system Permanent fallow grassland	P41	7	7	6	8
4	Kaukuntla	Agriculture (FM) Castor+Pigeonpea	P34	5	5	4	4
5	Palathurai	Horticulture (original) Tomato	P22	19	17	15	14

The content of mineral N varied between 5 mg kg^{-1} in the agricultural system of Kaukuntla series (P34) and 19 mg kg^{-1} in the horticultural system of Palathurai series (P22). The mineral N content of Hayatnagar series under low management was higher as compared to that of high-management because of the higher organic carbon content and a fairly low C:N ratio. The low content of MN in the soils of Kaukuntla series was primarily due to the low management by farmers.

3.2.3 Variation of mineral N content in different land-use systems

The variation in mineral N content of black and red soils at 0–30 cm depth in different land-uses is given in Figures 3.2.9 and 3.2.10, respectively. Under black soils, mineral N content in forest systems was lowest, obviously due to slow release of mineral nitrogen. Through the mineralization process soils under horticultural system were found to contain highest content of mineral N as compared to other systems. Similarly, under red soils, the forest system was found to contain low content of mineral N as compared to the other systems, where the soils under permanent fallow had the lowest content of mineral N (Figure 3.2.6).

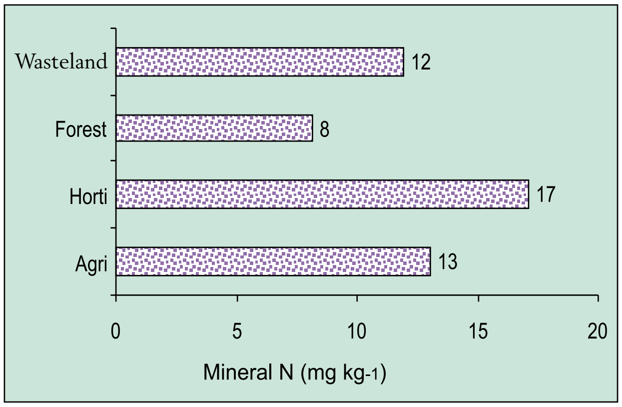


Figure 3.2.9. Mineral N content in black soils at 0–30 cm depth in different systems.

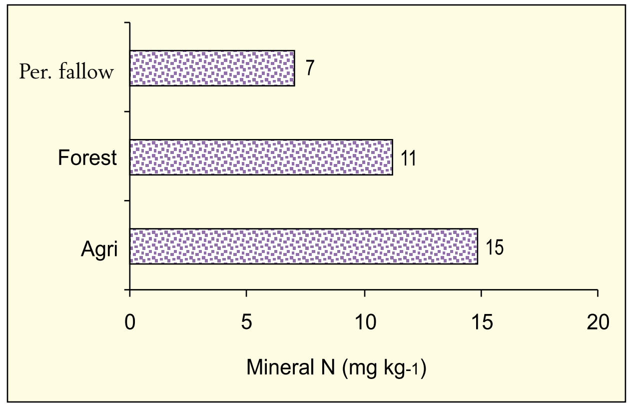


Figure 3.2.10. Mineral N content in red soils at 0–30 cm depth in different systems.

3.3 Nitrogen Stocks

3.3.1 Dynamics of soil nitrogen stocks in various bioclimatic zones

3.3.1.1 Black soils

The variation in the amount of total nitrogen and mineral nitrogen stocks at 0–30 cm depth in various bioclimatic zones is given in Figures 3.3.1 and 3.3.2.

The total N stocks at 0–30 cm depth varied between 1.45 Tg mha^{-1} in semi-arid (moist) and 2.38 Tg mha^{-1} in sub-humid (dry) zones. With decrease in rainfall, there was an increase in stocks of total N among different sub-humid and semi-arid regions. The total soil N stock in the arid zone was found to be higher than that in semi-arid (moist).

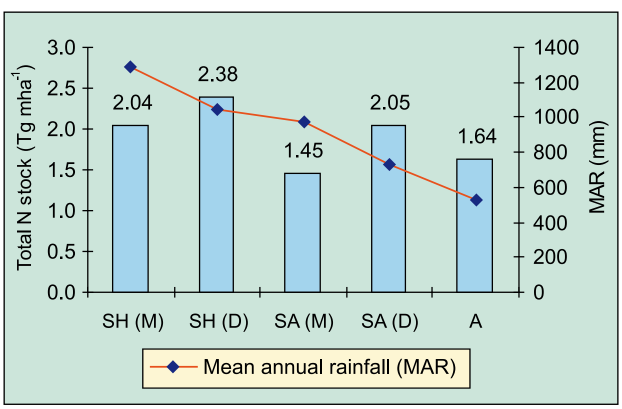


Figure 3.3.1. Total nitrogen stocks of black soils at 0–30 cm depth in different bioclimatic zones.

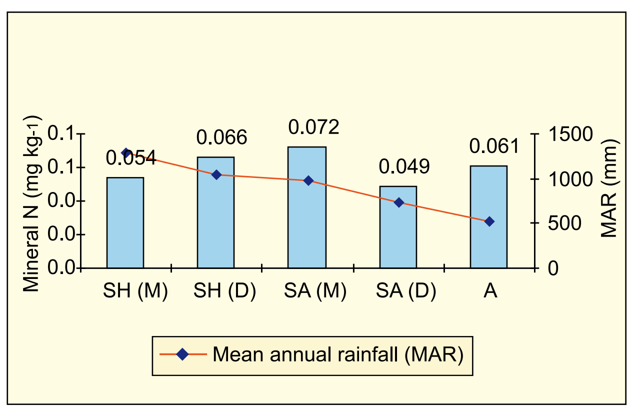


Figure 3.3.2. Mineral nitrogen stocks of black soils at 0–30 cm depth in different bioclimatic zones

The mineral N content of black soils at 0–30 cm depth varied from 0.049 to 0.072 Tg mha^{-1} among the various bioclimatic zones.

The maximum content was observed in semi-arid (moist) zone and was distinctly higher as compared to other zones, and this trend was somewhat different as compared to total soil N content in this zone.

3.3.1.2 Red soils

The variation in total and mineral nitrogen stocks at 0–30 cm depth in red soils in different bioclimatic zones is given in Figures 3.3.3 and 3.3.4, respectively. The total soil N stocks were largest at 3.20 Tg mha^{-1} in sub-humid (moist) zone. Among the semi-arid zones, with decrease in rainfall, stocks increased in semi-arid (dry) zone and it was 3.01 Tg mha^{-1}. Similarly, the mineral N stocks of red soils among various bioclimatic zones revealed that the content was highest in semi-arid (moist) soils and was less in soils of semi-arid (dry) zone.

Analysis of the total N stocks among soil types has shown that it was higher in red soils as compared to black soils and increased with increasing depth (Figure 3.3.5). However the mineral N stocks in black soils were higher than in red soils, and the MN content of black and red soils were same in 0–50 cm depth (Figure3.3.6).

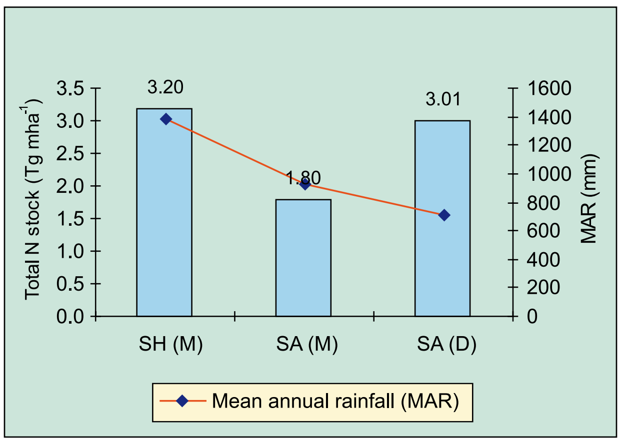


Figure 3.3.3. Total nitrogen stocks of red soils in 0–30 cm depth in different bioclimatic zones.

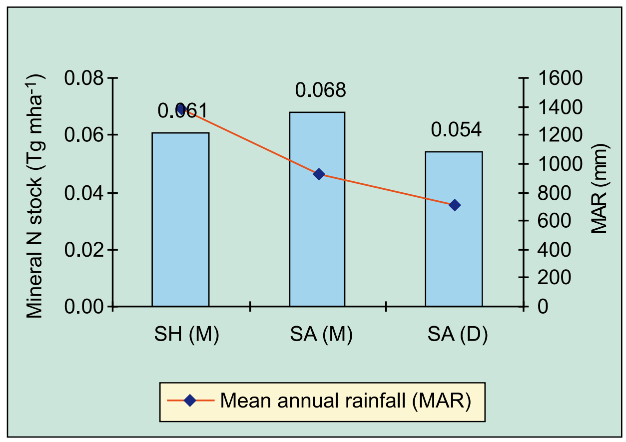


Figure 3.3.4. Mineral nitrogen stocks of red soils in 0–30 cm depth in different bioclimatic zones.

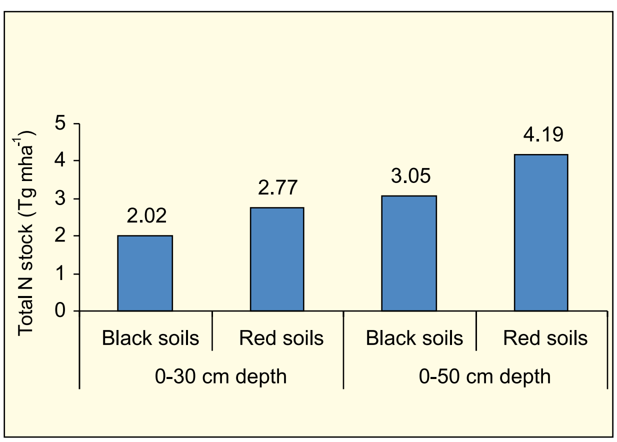


Figure 3.3.5. Total N stocks of black and red soils at various depths.

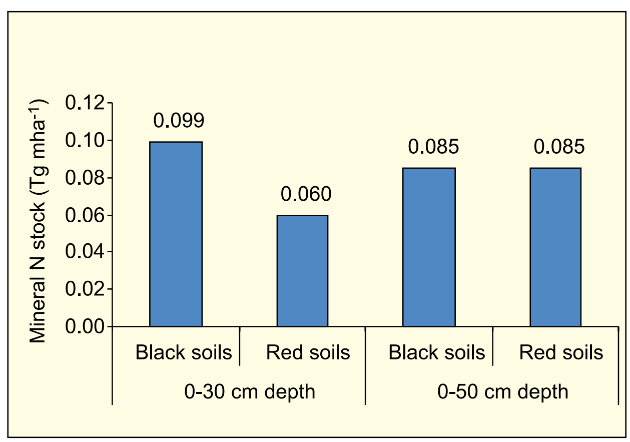


Figure 3.3.6. Mineral N stocks of black and red soils at various depths.

3.3.2 Total and Mineral N stocks in different benchmark spots

3.3.2.1 Sub-humid (moist)

Black Soils

The parameters for total N and MN stocks in different series and management systems in black soils of sub-humid moist bioclimatic zone are given in Table 3.3.1. Total and mineral N stocks at 30 cm depth of soil ranged from 1.7 to 2.54 Tg mha^{-1} and 0.03 to 0.09 Tg mha^{-1}, respectively. Results showed that Kheri soil series where agricultural system had soybean-wheat under low management, had lower nitrogen stocks, where as the same series under paddy-wheat rotation under high-management, showed higher values of total N stocks. The highly managed Kheri soils (P27) showed higher N stocks over forest soil series of Boripani (Figure 3.3.7). High-management systems generally led to higher N stocks and the low content of N stocks in P28 was due to poor management. In Nabibagh series agricultural system with S-W rotation under farmers' management had slightly higher N stocks than those in high-management and the trend was similar to those of TN content. Mineral N stocks showed considerable variation among the soil series, and higher mineral N stocks were found in Kheri series (P27) where higher total N stocks were observed and lower mineral N stock was noticed in Boripani series, with teak forests (Figure 3.3.8). The low mineral N content was the result of high C:N ratios of soils under forest system. The high mineral N stock of P27 was evident from the component crops of the system, ie, rice and wheat that received fertilizer N.

Table 3.3.1. Total N and mineral N stocks in black soils of sub-humid (moist) zone in SAT India.

			Total N stock (Tg/mha)				Mineral N stock (Tg/mha)			
			Soil depth (cm)				Soil depth (cm)			
Pedon no.	Series	Systems (crop)	0–30	0–50	0–100	0–150	0–30	0–50	0–100	0–150
P27	Kheri	AS (HM) Rice/ Wheat/Maize	2.54	3.66	6.11	9.24	0.09	0.14	0.25	0.35
P28	Kheri	AS (FM) Soybean-Wheat	1.70	2.59	4.94	6.31	0.04	0.06	0.10	0.13
P15	Boripani	Reserve forest teak	2.38	3.67	4.88	5.54	0.03	0.06	0.11	0.16
P5	Nabibagh	AS (HM) Soybean-Wheat	1.76	2.64	4.92	7.47	0.05	0.08	0.18	0.27
P6	Nabibagh	A (FM) Soybean-Wheat/Bengal gram	1.86	2.88	5.62	8.04	0.06	0.08	0.17	0.27
P4	Panjri	AS (HM) Cotton	2.02	30.1	5.04	6.68	0.06	0.09	0.17	0.25

Red Soils

Data pertaining to total N and mineral N stocks of red soils under sub-humid (moist) bioclimatic zone are given in Table 3.3.2. Results showed that at 0–30 cm depth, total N and mineral N stocks ranged from 1.77 to 4.45 Tg mha^{-1} and 0.01 to 0.05 Tg mha^{-1}, respectively. Dadarghugri series with high-management where forests (teak) had higher content of total N stocks, and in same series agriculture system (maize/mustard) under farmers' management had higher levels of mineral N or total N stocks (Figure 3.3.9). Reserved forest (sal) has 38.4% higher mineral N stock than teak forest (Figure 3.3.10). The higher stock in these series could be attributed to higher levels of organic matter. An inverse relationship was found between total N and mineral-N content of soils in P24 and P25.

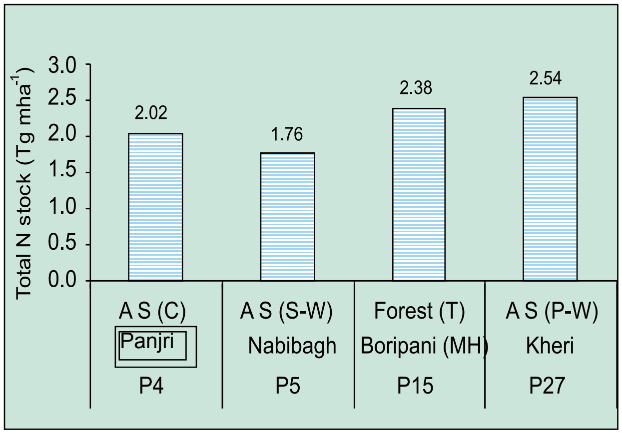


Figure 3.3.7 Total N stock in sub-humid (moist) bioclimatic system (0–30 cm) in black soils.

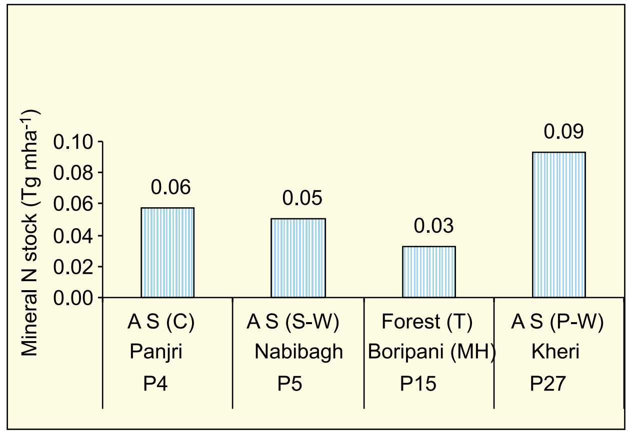


Figure 3.3.8 Mineral N stock in sub-humid (moist) bioclimatic system (0–30 cm) in black soils.

Table 3.3.2. Total N and mineral N stocks in red soils of sub-humid (moist) zone in SAT, India.

Pedon no.	Series	Systems (crop)	Total N stock (Tg/mha) Soil depth (cm) 0–30	0–50	0–100	0–150	Mineral N stock (Tg/mha) Soil depth (cm) 0–30	0–50	0–100	0–150
P23	Dadarghugri	AS (LM) Maize-Mustard (Pigeonpea)	4.44	6.72	13.07	19.09	0.01	0.13	0.23	0.32
P24	Dadarghugri	Forest system teak	4.45	5.73	9.02	12.15	0.04	0.05	0.07	0.08
P25	Karkeli	Forest system sal	2.12	2.85	4.72	6.89	0.05	0.07	0.10	0.11
P26	Karkeli	AS (LM) Sweet potato/ Minor millet (kodo)	1.77	3.16	6.34	8.89	0.05	0.07	0.09	0.12

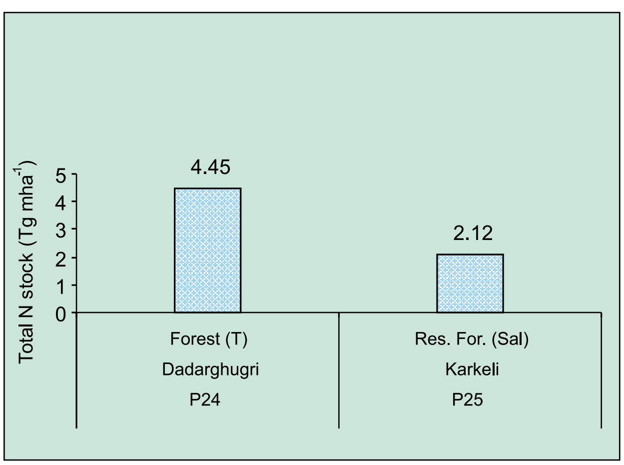


Figure 3.3.9. Total N stock in sub-humid (moist) bioclimatic system (0–30 cm) in red soils.

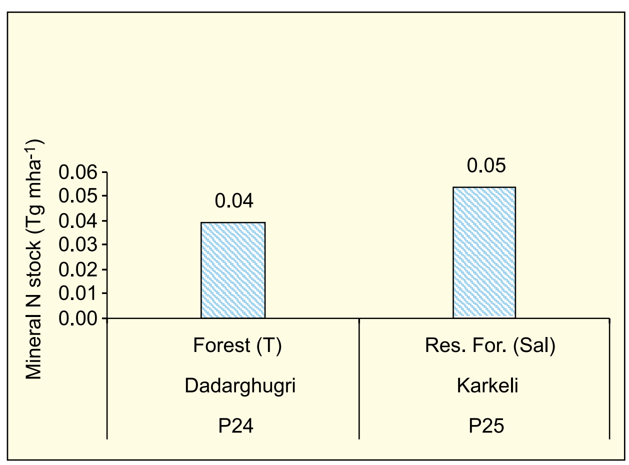


Figure 3.3.10. Mineral N stock in sub-humid (moist) bioclimatic system (0–30 cm) in red soils.

The low TN stock found in soils of Karkeli series under low management could be due to poor management and cultivation, which was taken up in the cleared forest land.

3.3.2.2 Sub-humid (dry)

Black Soils

The data on total and mineral N stocks in this zone are given in Table 3.3.3. Total and mineral N stocks at 0–30 cm depth of soil ranged from 1.84 to 2.92 Tg mha^{-1} and 0.05 to 0.08 Tg mha^{-1}, respectively. The total N stock was found largest in Nipani series (P48) followed by Linga (P1), Pangidi (P50) and Sarol (P7) (Figure 3.3.11). There was 78.9 % increase in total soil N stock in Nipani (P48) series under farmers' management over Sarol series (P8) where lowest total N stock was observed. Highest mineral N stock was observed in Pangidi series (P49) under FM. Mineral N stocks observed in Pangidi series (P49) were 65% higher than in Sarol series (P8). Horticultural system showed higher total and mineral N stocks as compared to agricultural system (Figure 3.3.12).

Table 3.3.3. Total and mineral N stocks in black soils of sub-humid (dry) zone in SAT, India.

Pedon no.	Series	Systems (crop)	Total N stock (Tg/mha) Soil depth (cm) 0–30	0–50	0–100	0–150	Mineral N stock (Tg/mha) Soil depth (cm) 0–30	0–50	0–100	0–150
P48	Nipani	AS (FM) Cotton+Pigeonpea and alternative Sorghum and Maize	2.92	3.93	6.28	8.37	0.06	0.07	0.12	0.15
P49	Pangidi	AS (FM) Soybean+ Pigeonpea	2.33	3.69	6.58	8.69	0.08	0.12	0.21	0.33
P50	Pangidi	AS (ITDA) Soybean	2.43	3.30	4.32	5.32	0.06	0.08	0.14	0.20
P7	Sarol	AS (HM) Soybean-Wheat	2.24	3.30	5.79	8.00	0.08	0.11	0.19	0.27
P8	Sarol	AS (FM) Soybean-Wheat	1.84	2.86	5.14	6.93	0.05	0.08	0.16	0.23
P9	Sarol	AS (HM)Soybean-Gram	2.15	3.16	5.50	7.58	0.06	0.09	0.17	0.25
P1	Linga	Horticulture (HM) Orange	2.53	3.73	5.95	7.93	0.08	0.11	0.17	0.24
P3	Linga	Horticulture (LM) Orange	2.44	3.58	6.42	8.77	0.07	0.10	0.18	0.24
P2	Linga	AS (FM) Soybean-Bengal gram/Wheat	2.54	3.79	6.62	8.69	0.07	0.11	0.20	0.29

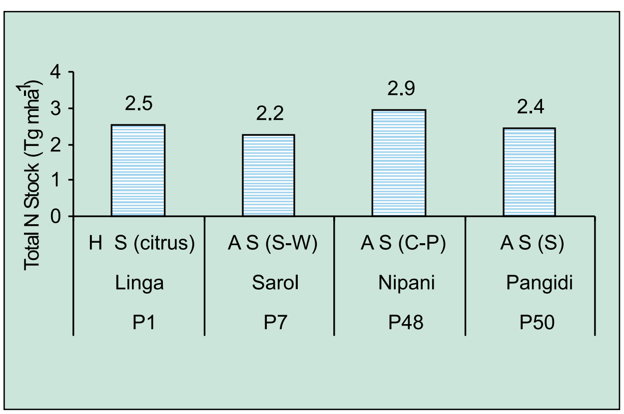


Figure 3.3.11. Total N stock in sub-humid (dry) bioclimatic system (0–30 cm) in black soils.

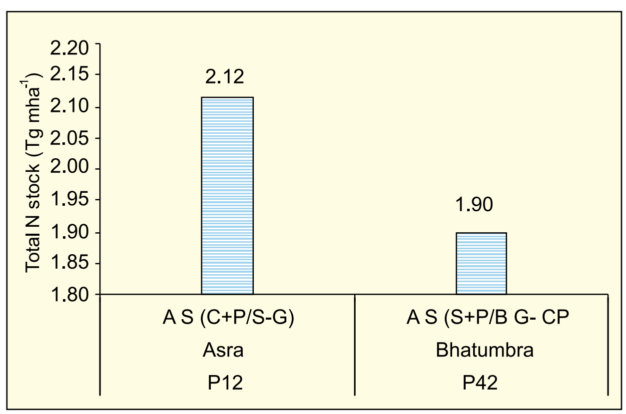


Figure 3.3.12. Mineral N stock in sub-humid (dry) bioclimatic system (0–30 cm) in black soils.

3.3.2.3 Semi-arid(moist)

Black soils

Data pertaining to total and mineral N stocks of black soils at various depths in semi-arid (moist) zone are given in the Table 3.3.4. Out of the two series in the black soils of this zone, Asra series (P12) under high-management levels recorded higher total N (2.1 Tg mha^{-1}) and mineral N (0.08 Tg mha^{-1}) followed by Bhatumbra series (P42) in agricultural system under farmers' management (Figures 3.3.13 and 3.3.14). Asra series (P12) had 11.6% higher levels of total N stocks and 23.5% higher levels of mineral N stocks over Bhatumbra series (P42). The agricultural system, viz., P10 and P11 under farmers' management in Asra series contained more or less similar stocks (Table 3.3.4).

Table 3.3.4. Total N and mineral N stocks in black soils of sub-arid (moist) zone in SAT, India.

			Total N stock (Tg/mha)				Mineral N stock (Tg/mha)			
			Soil depth (cm)				Soil depth (cm)			
Pedon no.	Series	Systems (crop)	0–30	0–50	0–100	0–150	0–30	0–50	0–100	0–150
P42	Bhatumbra	AS (FM) Sorghum+ Pigeonpea/Black gram-Chickpea	1.90	2.90	5.00	6.77	0.07	0.10	0.17	0.22
P10	Asra	AS (FM) Cotton-Green gram-Pigeonpea intercropping Cotton/PP	1.67	2.58	4.51	6.21	0.06	0.09	0.18	0.25
P11	Asra	AS (FM) Soybean-Pigeonpea intercropping Soy/PP	1.75	2.70	5.17	7.62	0.08	0.10	0.16	0.26
P12	Asra	AS (HM) Soybean-G-CO-PP	2.12	3.19	5.63	7.83	0.08	0.11	0.19	0.26

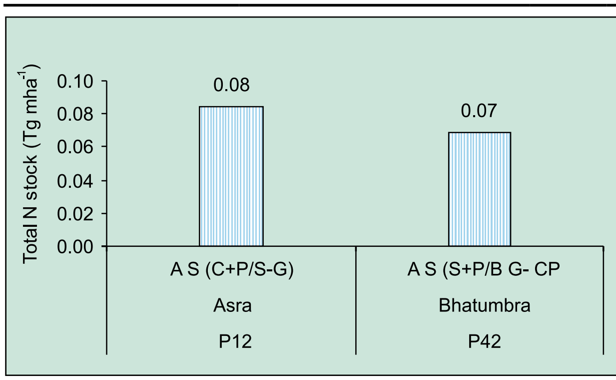


Figure 3.3.13. Total N stocks in semi-arid (moist) bioclimatic system (0–30 cm) in black soils.

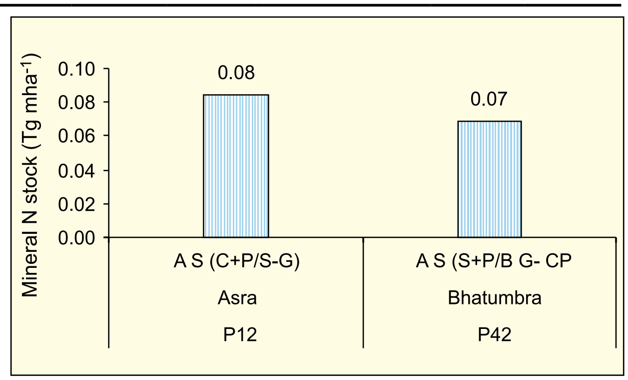


Figure 3.3.14. Mineral N stocks in semi-arid (moist) bioclimatic system (0–30 cm) in black soils.

Red Soils

Total N and mineral N stocks of red soils of semi-arid (moist) zone at various depths are given in Table 3.3.5. The stocks ranged between 1.53 to 2.31 Tg mha^{-1} for total N and 0.06 to 0.09 Tg mha^{-1} for mineral N. Highest total N and mineral N stocks were recorded in farmers' management (P16). Under this same series, farmers' management recorded 50.9% higher level of total N and 52.6% higher levels of mineral N over high-management system. (Figures 3.3.15 and 3.3.16).

Table 3.3.5. Total N and mineral N stocks in red soils of semi-arid (moist) zone in SAT, India

Pedon no.	Series	Systems (crop)	Total N stock (Tg/mha)				Mineral N stock (Tg/mha)			
			Soil depth (cm)				Soil depth (cm)			
			0–30	0–50	0–100	0–150	0–30	0–50	0–100	0–150
P16	Vijayapura	AS (FM) Finger millet	2.31	2.27	6.35	8.33	0.09	0.12	0.20	0.29
P17	Vijayapura	AS (original) Pulses	1.55	2.36	4.00	5.19	0.06	0.09	0.18	0.26
P18	Vijayapura	AS (HM) Finger millet	1.53	2.27	3.87	5.08	0.06	0.09	0.15	

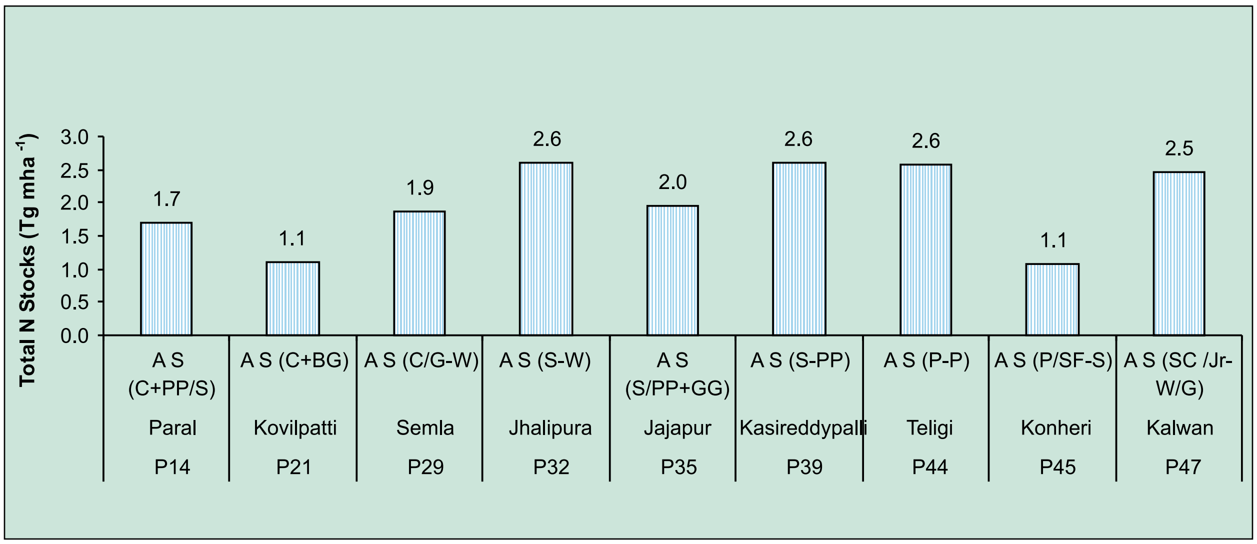


Figure 3.3.15. Total N stock under semi-arid (dry) bioclimatic system (0–30 cm) in black soils.

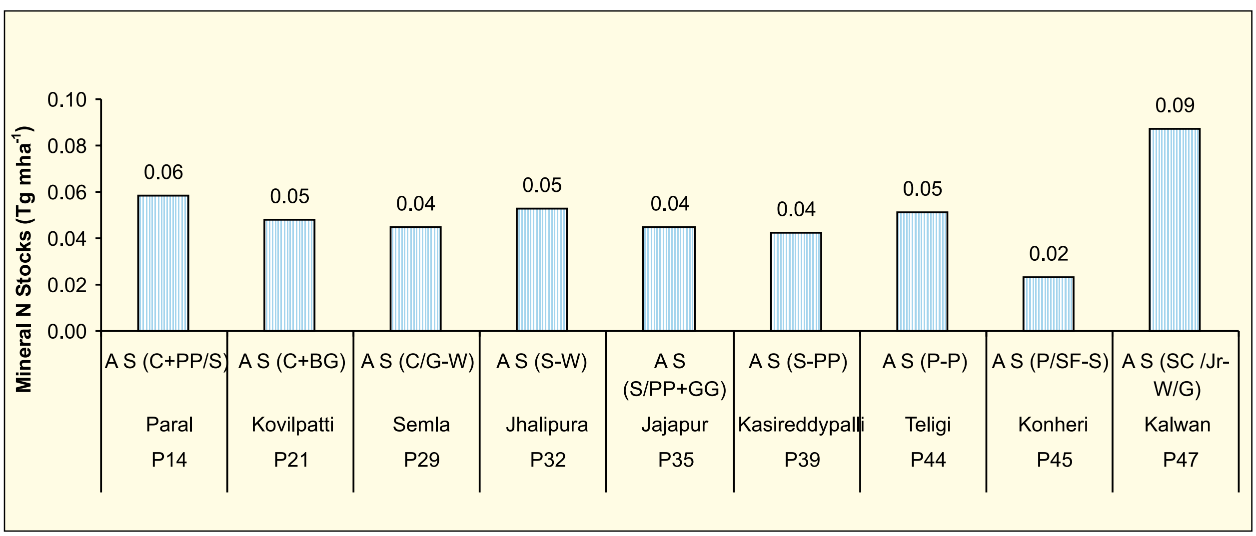


Figure 3.3.16. Mineral N stock under semi-arid (dry) bioclimatic system (0–30 cm) in black soils.

3.3.4 Semi-arid (dry)

Black Soils

Data on total N and mineral N stocks of black soils of semi-arid dry zone at 0–30 cm depth of soil are given in Table 3.3.6. Among different soil series, total N stocks ranged from 1.00 Tg mha^{-1} in soils of Kovilpatti series (P19) to 4.65 Tg mha^{-1} in soils of Jajapur series under paddy system (P36). In general, Kovilpatti series was found to have low content of total N stock while soils under Konheri series was found to have lowest mineral N stock. The absence of legumes and the inherent low TN content of soils in Kovilpatti series could be the reasons for low TN stocks. High mineral N stock was observed in soils of Jhalipura (P33) and Kalwan (P47), while in most of the other series the stocks ranged from 0.04 to 0.06 Tg mha^{-1}. The total N stock of soils under Jhalipura series (P32), Kasireddypalli series (P39) and Teligi (P44) series were observed to be high as compared to other soil series.

Table 3.3.6. Total and mineral N stocks in black soils of semi-arid (dry) zone in SAT, India.

			Total N stock (Tg/mha)				Mineral N stock (Tg/mha)			
			Soil depth (cm)				Soil depth (cm)			
Pedon no.	Series	Systems (crop)	0–30	0–50	0–100	0–150	0–30	0–50	0–100	0–150
P32	Jhalipura	AS (FM) Soybean-Wheat	2.61	3.44	5.36	7.25	0.05	0.08	0.14	0.23
P33	Jhalipura	AS (FM II) Paddy-Wheat	2.26	3.13	4.46	5.53	0.07	0.11	0.20	0.26
P13	Paral	AS (LM)Cotton-Sorghum-Pigeonpea	1.43	2.28	4.47	6.59	0.06	0.10	0.19	0.23
P14	Paral	AS (HM)Cotton-Pigeonpea-Sorghum	1.70	2.60	3.84	5.28	0.06	0.09	0.16	0.21
P35	Jajapur	AS (FM I) Sorghum-Pigeonpea-Green gram	1.97	2.89	4.75	6.23	0.04	0.06	0.11	0.15
P36	Jajapur	AS (FM II) Paddy-Paddy	4.65	5.82	7.73	8.81	0.06	0.08	0.09	0.14
P39	Kasireddy palli	AS (HM) Soybean-Pigeonpea intercropping	2.61	3.68	6.03	7.95	0.04	0.06	0.14	0.19
P40	Kasireddy palli	AS (TM)Fallow-gram	1.90	2.91	5.28	7.29	0.04	0.05	0.07	0.10
P45	Konheri	AS (FM) Pigeonpea/ Sunflower Fallow-Sorghum	1.08	1.89	3.53	5.21	0.02	0.04	0.08	0.14
P46	Konheri	AS (LM)Fallow-Sorghum	1.76	2.89	5.60	6.74	0.02	0.05	0.10	0.16
P47	Kalwan	AS (FM) Maize-Sugarcane/ Onion/Wheat	2.47	3.50	5.47	6.20	0.09	0.11	0.17	0.19
P19	Kovilpatti	AS (original) Sorghum	1.00	1.65	3.20	4.52	0.04	0.07	0.15	0.21
P20	Kovilpatti	Wasteland	1.18	1.82	3.58	5.00	0.05	0.08	0.15	0.23
P21	Kovilpatti	AS (HM) Cotton	1.11	1.87	3.60	4.91	0.05	0.08	0.15	0.24
P29	Semla	AS (FM) Groundnut /Cotton	1.88	2.73	4.31	5.90	0.04	0.07	0.13	0.26
P43	Teligi	AS (LM) Paddy-Paddy	2.61	3.72	5.80	7.71	0.03	0.04	0.09	0.13
P44	Teligi	AS (HM) Paddy-Paddy	2.58	3.61	5.49	7.10	0.05	0.07	0.10	0.11

Red Soils

Data on total N and mineral N stocks of red soils in semi-arid (dry) bioclimatic zone are given in Table 3.3.7. The mineral N stocks in soils of different series are given in Figures 3.3.17 and 3.3.18. The total N stocks ranged from 2.06 Tg mha^{-1} in Palathurai series (P22) to 3.92 Tg mha^{-1} in Patancheru series under permanent fallow system (P41). The mineral N stocks ranged from 0.02 in Kaukuntla, Palathurai series (P34) to 0.09 Tg mha^{-1} in series (P22). Patancheru series under permanent grassland system recorded highest nitrogen stocks and horticultural system of Palathurai series was found to have highest mineral N stocks. The soils of P22 are cultivated for vegetables and are not intensively cultivated. The high CEC of soil which might have resulted in more adsorption of ammonium can explain the high content of MN in those soils.

Table 3.3.7 Total N and mineral N stocks in red soils of semi-arid (dry) zone in SAT, India.

			Total N stock (Tg/mha)				Mineral N stock (Tg/mha)			
			Soil depth (cm)				Soil depth (cm)			
Pedon no.	Series	Systems (crop)	0–30	0–50	0–100	0–150	0–30	0–50	0–100	0–150
P37	Hayatnagar	AS (HM) Sorghum-Castor	2.84	5.28	8.65	10.72	0.05	0.06	0.09	0.12
P38	Hayatnagar	AS (LM) Sorghum-Castor	3.05	4.94	7.45	8.06	0.08	0.12	0.19	0.26
P41	Patancheru	Fallow system Permanent fallow grassland	3.92	6.28	10.12	20.18	0.03	0.05	0.10	0.20
P34	Kaukuntla	AS (FM) Castor+Pigeonpea	3.19	5.18	9.20	12.21	0.02	0.04	0.07	0.20
P22	Palathurai	Horticulture (original) Tomato	2.06	3.28	5.57	8.10	0.09	0.14	0.24	0.33

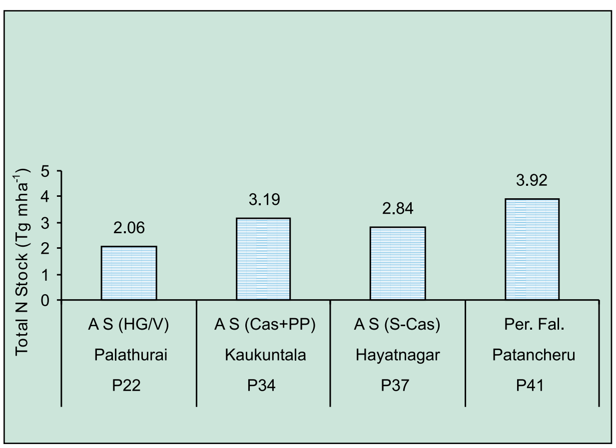


Figure 3.3.17. Total N stock in semi-arid (dry) bioclimatic system (0–30 cm) in red soils.

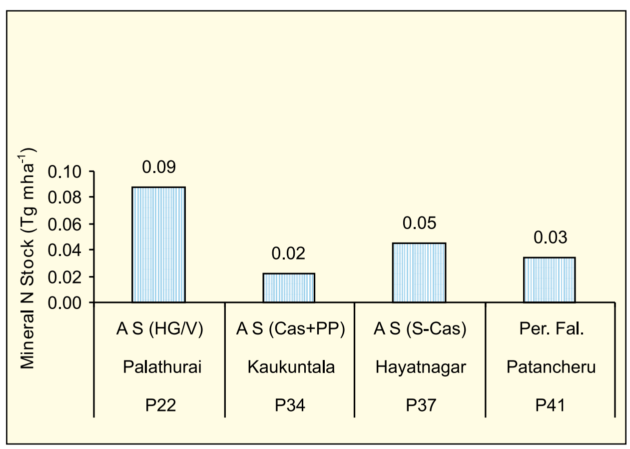


Figure 3.3.18. Mineral N stock in semi-arid (dry) bioclimatic system (0–30 cm) in red soils.

3.3.2.5 Arid Black Soils

Data on total and mineral N stocks at various depths of black soils of arid zone are given in Table 3.3.8. The total N stocks range from 0.66 in soils of Sokhda series (P31) to 2.51 Tg mha^{-1} in Nimone series under agriculture (P51). The mineral N stocks varied from 0.03 in Nimone series (P52) to 0.09 Tg mha^{-1} in P51 in the same series. Nimone series, which was under high-management systems. recorded high N stocks. The soils of P51 are under high, management, which could be the reason for higher nutrient stocks. The soils under P52 were cultivated for more exhaustive crops like sugarcane, wheat, etc, which could be the reason for the low MN content in those soils.

Table 3.3.8. Total N and mineral N stocks in black soils of arid zone in SAT, India.

			Total N stock (Tg/mha)				Mineral N stock (Tg/mha)			
			Soil depth (cm)				Soil depth (cm)			
Pedon no.	Series	Systems (crop)	0–30	0–50	0–100	0–150	0–30	0–50	0–100	0–150
P30	Sokhda	AS (FM I) Cotton/Pearl millet	1.19	2.00	4.25	5.48	0.07	0.10	0.20	0.23
P31	Sokhda	AS (FM II) Cotton-Pearl millet/Linseed	0.66	1.11	2.52	3.65	0.05	0.08	0.16	0.25
P51	Nimone	AS (HM) Cotton-Wheat/ Chickpea (Irrigated)	2.51	3.97	7.09	9.78	0.09	0.13	0.16	0.19
P52	Nimone	AS (FM) Sugarcane-Soybean/Wheat/Chickpea	2.19	3.37	5.43	6.76	0.03	0.05	0.09	0.11

3.3.3 Variation in soil nitrogen stocks under different systems

The total nitrogen stocks in black soils at 0–30 cm depth in various land-use system is given in Figure 3.3.19.

Highest total N stocks were observed in horticultural and forest systems (2.4–2.5 Tg mha^{-1}) followed by agricultural systems. Results emphasise the need to improve the total N stocks through various management practices like organic matter addition, fertilizer application and adoption of suitable cropping systems, which add more carbon through root biomass. The low total N stocks were observed in soils of wasteland system obviously due to the lack of various practices which add nutrients to the soil. Similarly, the total N stocks in red soils at 0–30 cm depth were higher in forest systems and lowest in agricultural systems (Figure 3.3.20).The soils under permanent fallow were found to have the maximum total N stocks (3.9 Tg mha^{-1}) compared to other systems.

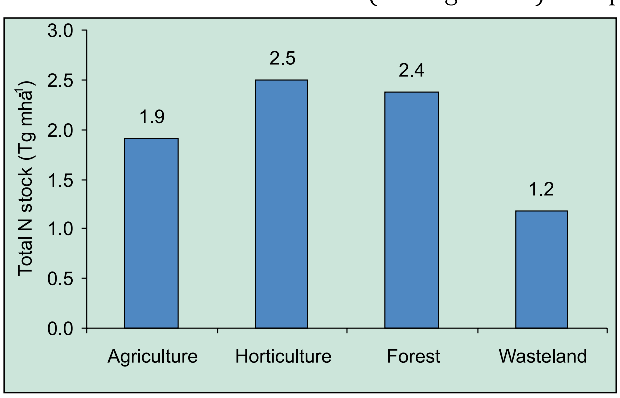


Figure 3.3.19. Total N stocks in black soils at 0–30 cm depth in different land-use systems.

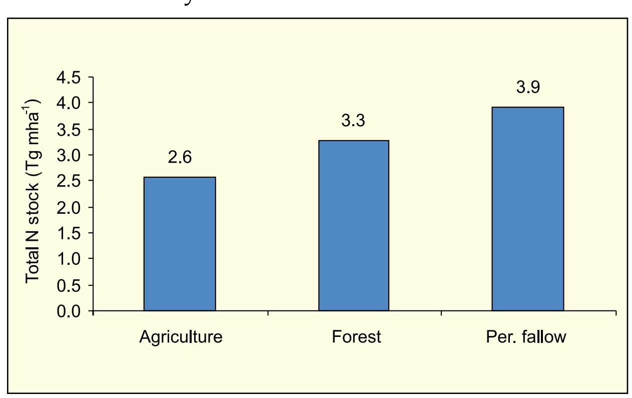


Figure 3.3.20. Total N stocks in red soils at 0–30 cm depth in different land-use systems.

The mineral N stocks in black soils at 0–30 cm depth in various land-use systems are given in Figure 3.3.21. Soils of agricultural systems were found to have highest content of mineral N stocks (0.14 Tg mha^{-1}) which was lowest under forest system. It was observed that the mineral N stock was highest in agricultural system, followed by horticultural and forest systems. The application of fertilizer inputs was highest in horticultural and agricultural systems and lowest under forest. The mineral N content of wasteland soils was slightly higher than that of the forest due to the release of mineral N by mineralization. The trend of mineral N distribution in red soils was similar to that of black soils with respect to agricultural and forest systems (Figure 3.3.22). The mineral N content of red soils under permanent fallow was the lowest.

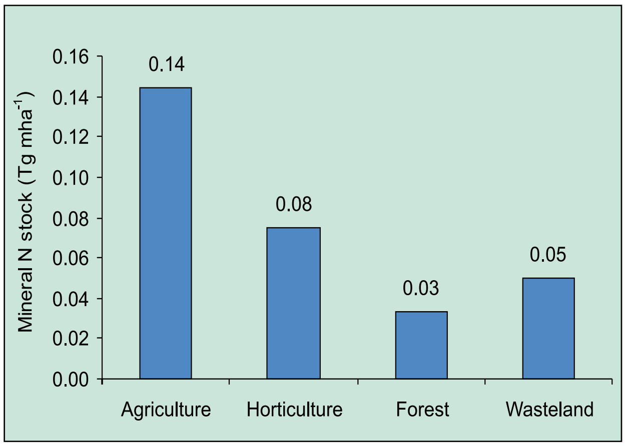


Figure 3.3.21. Mineral N stocks in black soils at 0–30 cm depth in different land-use systems.

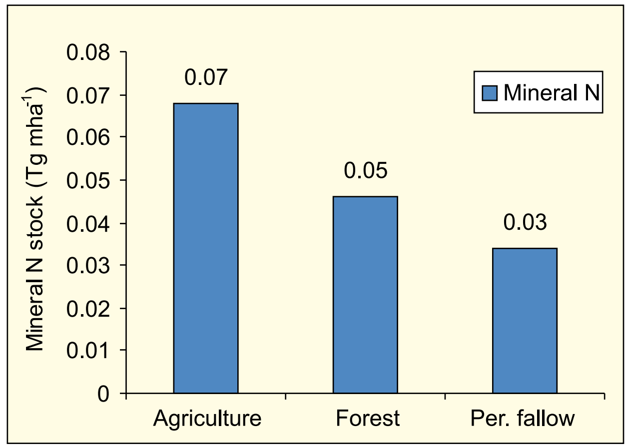


Figure 3.3.22. Mineral N stocks in red soils at 0–30 cm depth in different land-use systems.

3.4 Total Phosphorus

Total phosphorus measures the amount of phosphorus tied up in soil mineral particles (which come from the break down of rocks) and with organic matter. Total phosphorus is generally much higher than the amount of phosphorus actually available for plant uptake. Unlike nitrogen, phosphorus is involved in geochemical (mineral) reactions that may make phosphorus less available for biotic cycling.

Depending upon the parent material and extent of soil weathering, the P content of soil in the world ranges from 0.02 to 0.5%. Variations in total P are mainly due to different parent-rock material types. Soils with higher phosphorus levels are derived from basaltic rocks because these rocks have higher-than-average levels of phosphorus whilst those developed from granite or sandstone have low P. The total P in Indian soils varies from 0.01 to 0.2% with an average of 0.02 to 0.08% for most agricultural soils (Kanwar and Grewal 1974; Khanna and Pathak 1982). The total P content of most Indian soils is low compared to world standards and many soils require phosphate fertilizers to optimize production. Generally, total P is poorly correlated with available P. The concentration of P in soil solution is very low (0.1 ppm) and since a number of reactions affect availability, P deficiency is a widespread problem in India. As an example, the unweathered calcareous soils of dry regions often have high P content due to general lack of leaching and the presence of appreciable amounts of P in the form of apatite. The P content of many soils has been altered by cropping, addition of animal manures and fertilizers. Thus, high amounts of P in the parent material and the relatively low amounts in the profile suggest that losses through leaching were extensive during weathering and soil formation, which provides more information to aid in phosphorus management and carbon sequestration in dryland soils. Thus, characterization of total P in surface layers of semi-arid tropical (SAT) soils of India can be used to identify areas where natural soil fertility is low and fertilizer inputs would be required for maximum root and shoot biomass and for increased organic matter content and thus for enhanced carbon sequestration in these soils. This section focuses on the variations in the content of total soil P as influenced by climate and its relationships with organic carbon and other soil properties. The total P content of Indian semi-arid tropical soils ranged from 0.014 to 0.186% (per cent by weight). These soils include black soils Vertisols, vertic intergrades of Inceptisols and red soils Alfisols. In black soils, with the parent materials as basaltic alluvium, weathered basalt, gneissic alluvium and basaltic alluvium of Cuddapah limestone, weathered granite-gneiss mixed with or without alluvium, the total P content varied from 0.014 to 0.064%. In red soils, which are derived from weathered basalt (Dadarghugri series), weathered sandstone, weathered granite-gneiss, granites, gneisses and weathered gneiss (Palathurai series), the total P content varied from 0.013 to 0.186%. With the exception of Dadarghugri and Palathurai series, the total P content of red soils was generally lower than that of black soils.

3.4.1 Variation of total P in different bioclimatic zones

3.4.1.1 Black soils

The average content of total P in 0–30 cm soil depth in different zones ranged from 275 mg kg^{-1} in sub-humid (moist) to 459 mg kg^{-1} in semi-arid (moist) zone (Figure 3.4.1). There was a considerable increase in total P content with decrease in mean annual rainfall (MAR) from sub-humid (moist) to semi-arid (moist) zone and then total P decreased. The soils of high-rainfall zone contain less organic matter and more Fe and Al due to leaching of the bases, which could be the reason for the low content of total P in this zone. The content of TP was less in soils of SA (D) due to the presence of inherently low-content soil series such as Jajapur, Kasireddypalli and Kovilpatti. The total P content was found to be higher in the surface as compared to lower depths except where the P-bearing minerals are found in the profile. As discussed previously, at any time most soil P is associated with primary and secondary mineral and organic matter. Highest values for total P in a profile is found at the surface due to biocycling and subsequent accumulation of P in organic forms. The amount of phosphorus in sub-surface horizons is generally of the same order as found in surface layer. As the mineral forms are associated with weathering and are concentrated mostly in the fine-size fractions (clay size and lesser) and in organic forms, the profile as well as the surface-horizons trends for P can be related to carbon and clay content. Analysis of total P and organic carbon content of black soils in various bio-climatic zones revealed the positive relationship between these two parameters (Figure 3.4.2).

The average distribution of clay in different bioclimatic zones showed a minimum of 48% in arid and a maximum of 66% in sub-humid (dry), which was closely followed by 64% in semi-arid (moist). Figure 3.4.3 shows the relationship between total P and clay content in soils of various bioclimatic zones. It indicates the positive relationship between clay content and total P with a decrease in the rainfall from sub-humid (moist) to semi-arid (moist), after which there was a decrease in the clay content. The relationship between total P and organic carbon and clay as well as with fine clay in black soils was positive and significant ($r=0.42^{**}$, and 0.38^{*} respectively). Similarly, the total N content of the black soils increased with total P in sub-humid (moist) and sub-humid (dry) zones as shown in the Figure 3.4.4 and the correlation coefficient was found to be positive but not significant ($r=0.23$).

3.4.1.2 Red soils

The average total P content of red soils in 0–30 cm depth varied from 184 to 854 mg kg^{-1} in various bioclimatic zones (Figure 3.4.5). The TP content was maximum in sub-humid (moist) and minimum in the semi-arid (moist). The difference in total P between the two zones can be attributed to the parent material: weathered basalt and sandstone in case of sub-humid (moist) and

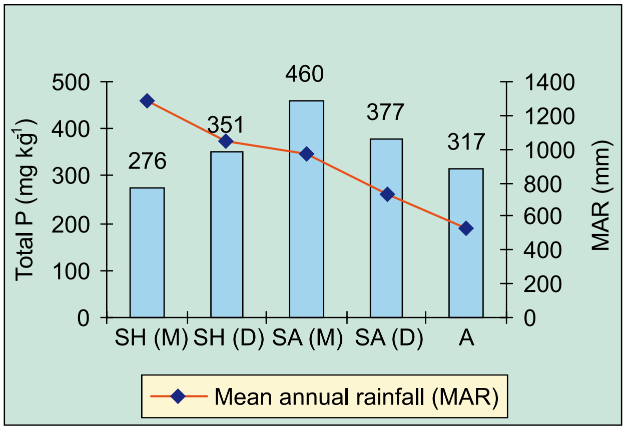


Figure 3.4.1. Total phosphorus content of black soils at 0–30 cm depth in different bioclimatic regions

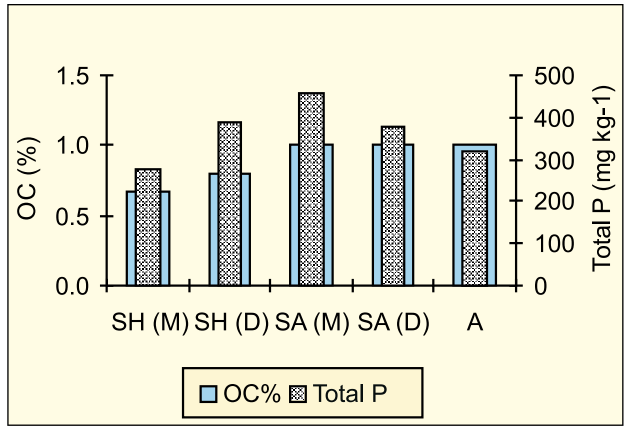


Figure 3.4.2. Status of total P in relation to OC% of soils at 0–30 cm depth in different bioclimatic zones in black soils

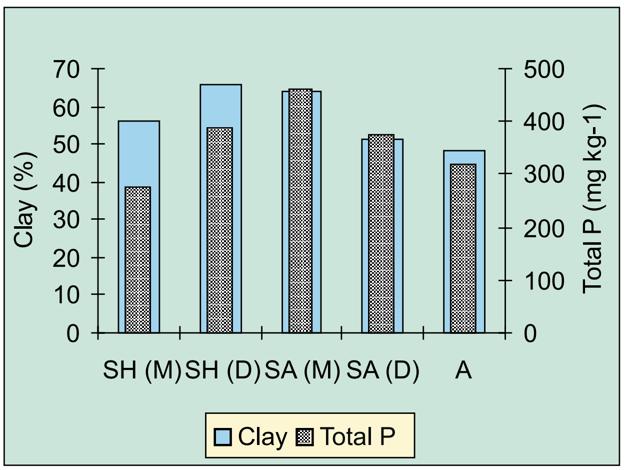


Figure 3.4.3. Status of total P in relation to clay content of soils at 0–30 cm depth in different bioclimatic zones in black soils

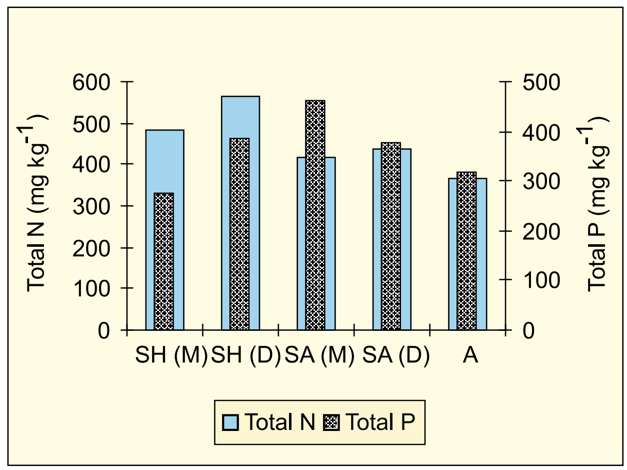


Figure 3.4.4. Status of total P in relation to total N content of soils at 0–30 cm depth in different bioclimatic zones in black soils

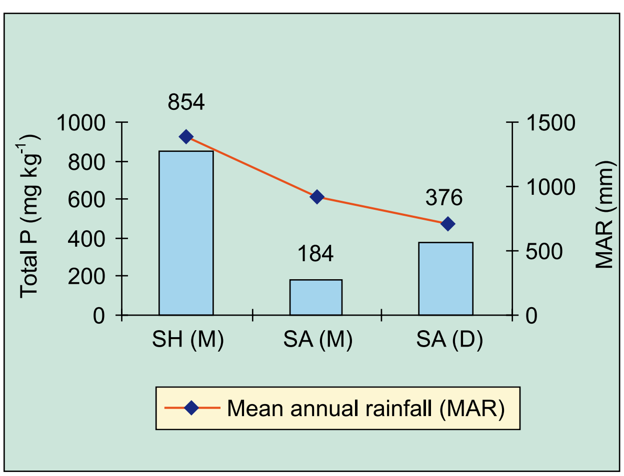


Figure 3.4.5. Total phosphorus content of red soils at 0–30 cm depth in different bioclimatic zones.

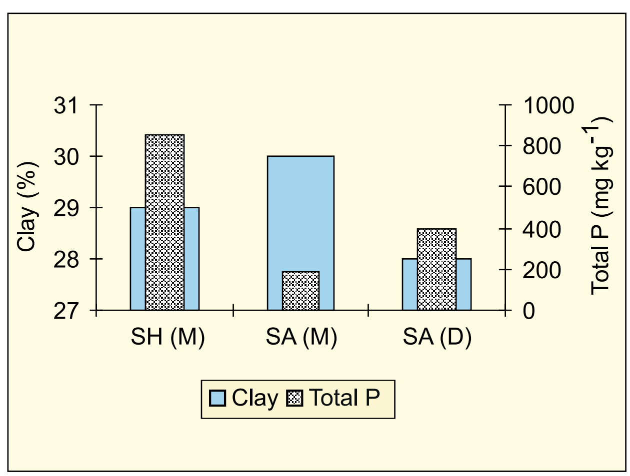


Figure 3.4.6. Status of total P in relation to clay content of soils at 0–30 cm depth in different bioclimatic zones in red soils.

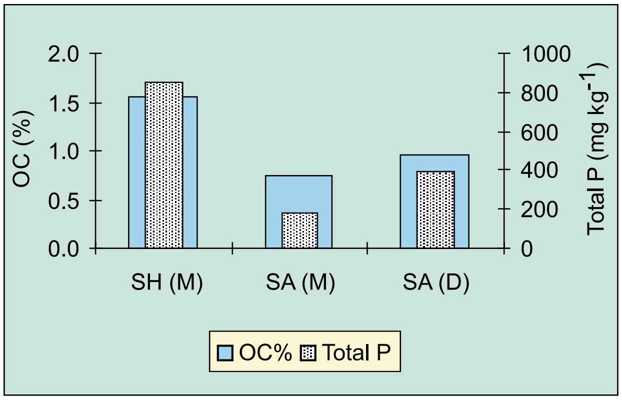


Figure 3.4.7. Status of total P in relation to OC% content of soils at 0–30 cm depth in different bioclimatic zones in red soils.

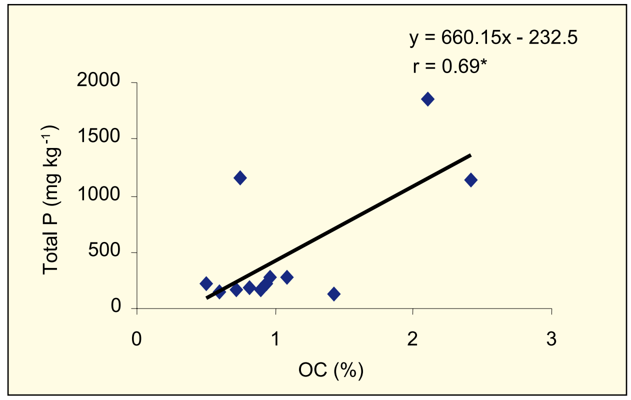


Figure 3.4.8. Relationship of Total P with SOC in red soil at 0–30 cm depth.

weathered granite-gneisses in case of semi-arid (moist). The red soils have less clay content and less total N and organic carbon content than black soils in all bioclimatic zones. The relationship between clay and organic carbon content with total P is presented in figures 3.4.6 and 3.4.7. The total P content in red soils was also positively and significantly correlated with organic carbon in 0–30 and 0–50 cm depth (Figure 3.4.8).

3.4.2 Variation in total P in different benchmark locations

Black Soils

3.4.2.1 Sub-humid (moist)

The total P content of black soils at various depths in sub-humid (moist) zone is given in Table 3.4.1.

Table 3.4.1. Profile distribution of total P concentration in various benchmark locations of black soils under sub-humid (moist) zone.

Sl. no.	Series	System	P. no.	Total P ($mg\ kg^{-1}$) Soil depth (cm) 0–30	0–50	0–100	0–150
1.	Kheri	Agriculture (HM) Rice/Wheat/Maize	P27	383	326	265	249
2.	Kheri	Agriculture (FM) Soybean-Wheat	P28	225	211	206	209
3.	Boripani	Reserve forest teak	P15	152	155	356	444
4.	Nabibagh	Agriculture (HM) Soybean-Wheat	P5	336	308	292	292
5.	Nabbagh	Agriculture (FM) Soybean-Wheat, Bengal gram	P6	355	346	337	331
6.	Panjri	Agriculture (HM) Cotton	P4	206	203	200	190

The total P concentration in 0–30 cm depth in Kheri series (P27) was highest (383 $mg\ kg^{-1}$) and the lowest P concentration of 152 $mg\ kg^{-1}$ was observed in Boripani series (P15). The large difference in P concentration between these two benchmark spots could be attributed to the parent material and the extent of weathering. The parent material of Kheri is basaltic alluvium, while the soils of Boripani developed from weathered basalt. Initially, all P in the soil will be in the form of calcium appatites.

With time, soil P is released and incorporated into the biomass and finally incorporated into the organic fractions. With time and weathering, a greater proportion of total P is converted to organic forms. The soils of P4 were also found to contain low TP, which could be due to low SOC content. The content of total P was higher in the surface than in the sub-surface and bottom layers, except in case of P15 where the content of TP in 0–150 cm was high due to the presence of P-rich materials at this depth.

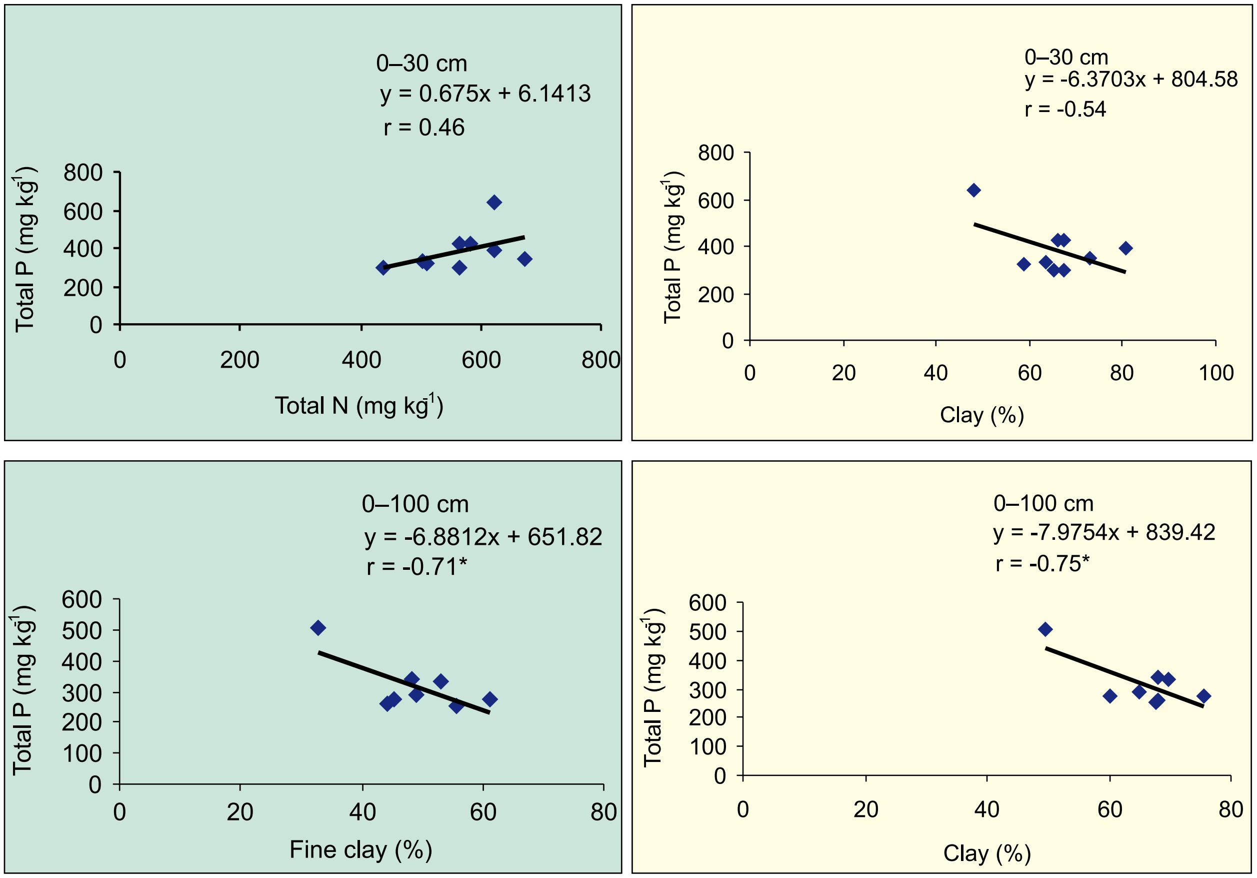
3.4.2.2 Sub-humid (dry)

The total P concentration of black soils at various depths in sub-humid (dry) zone is given in Table 3.4.2.

Table 3.4.2. Profile distribution of total P in black soils in various benchmark spots under sub-humid (dry) zone.

Sl. no.	Series	System	P. no.	Total P (mg kg^{-1}) Soil depth (cm) 0–30	0–50	0–100	0–150
1.	Nipani	Agriculture (FM) C+PP and alternative Sorghum & Maize	P48	638	565	505	494
2.	Pangidi	Agriculture (FM) Soybean+Pigeonpea	P49	348	320	275	254
3.	Pangidi	Agriculture (ITDA) Soybean	P50	391	480	642	696
4.	Sarol	Agriculture (HM) Soybean-Wheat	P7	335	294	263	248
5.	Sarol	Agriculture (FM) Soybean-Wheat	P8	300	291	286	274
6.	Sarol	Agriculture (HM) Soybean-Bengal gram	P9	325	301	277	286
7.	Linga	Horticulture (HM) Orange	P1	423	387	333	311
8.	Linga	Horticulture (LM) Orange	P3	427	387	343	324
9.	Linga	Agriculture (FM) Soybean-Bengal gram/Wheat	P2	296	279	255	255

The total P concentration at 0–30 cm varied between a low of 296 mg kg^{-1} in Linga (P2) to 638 mg kg^{-1} in Nipani (P48) soils. The reasons for the above variation in total P concentration could be due to parent materials, viz., basaltic alluvium of Cuddapah limestone and gneissic alluvium in case of P48, which accounted for the high content of TP, and the adoption of nutrient-exhaustive crops such as wheat in the soils of P2 that account for the low-P content. The soils of Sarol series were found to have comparatively moderate levels of TP; the reasons could be the balance between fertilizer application and cultivation of nutrient-exhaustive crops such as wheat. Knowledge of exact levels of fertilizer applied under horticulture systems of Linga series will help to further explain the higher levels of TP in this series. The average total P as well as the organic carbon content was intermediate between those of sub-humid (moist) and semi-arid (moist), which again reflects the positive relationship of total P and organic carbon. The correlation coefficient between total P with total N (Figure 3.4.9) and with clay (Figure 3.4.10) showed a positive and negative relationship, respectively, though both are not significant. The other parameters also failed to exert any positive influence on the total P concentration in this zone. However, a significant negative correlation of total P concentration with fine clay (Figure 3.4.11) and with clay (Figure 3.4.12) was observed at 0–100 cm.



Figures 3.4.9 to 3.4.12. Relationship of total P with organic carbon and clay content of black soils at different depths in sub-humid (dry) zone.

3.4.2.3 Semi-arid (moist)

The total P concentration of black soils at various depths in semi-arid (moist) zone is given in Table 3.4.3.

Table 3.4.3. Profile distribution of total P concentration in black soils in various benchmark spots under semi-arid (moist) zone.

				Total P (mg kg^{-1})			
				Soil depth (cm)			
Sl. no.	Series	System	P. no.	0–30	0–50	0–100	0–150
1.	Bhatumbra	Agriculture (FM) Sorghum+ Pigeonpea/ Black gram-Chickpea	P42	433	376	300	251
2.	Asra	Agriculture (FM) Cotton-Green gram-Pigeonpea intercropping Cotton/PP	P10	497	491	479	473
3.	Asra	Agriculture (FM) Soybean-Pigeonpea intercropping Soy/PP	P11	515	496	482	481
4.	Asra	Agriculture (HM) Soybean-Gram-Cotton-Pigeonpea	P12	396	372	342	339

Asra and Bhatumbra are the major series in this zone. The total P concentration in 0–30 cm soil depth varied between 396 to 515 mg kg^{-1} in Asra series. The variation within the Asra series itself was found to be 30% (P12 vs. P11), which can be attributed to variations in management. The TP concentration of soils is closely correlated with relief features other than parent material and geology, which could have caused the variation of TP in P11 and P12 series. The soil pH was also acidic in case of P12. Figures 3.4.2 and 3.4.3 show the highest total P content in this zone. The mean organic carbon and clay contents were also found to be highest.

3.4.2.4 Semi-arid (dry)

The total P concentration of soils in semi-arid (dry) zone is presented in Table 3.4.4.

Table 3.4.4. Profile distribution of total P concentration in various benchmark locations of black soils under semi-arid (dry) zone.

				Total P (mg kg^{-1})			
				Soil depth (cm)			
Sl. no.	Series	System	P. no.	0–30	0–50	0–100	0–150
1.	Jhalipura	Agriculture (FM) Soybean-Wheat	P32	479	433	344	321
2.	Jhalipura	Agriculture (FM II) Paddy-Wheat	P33	427	392	306	273
3.	Paral	Agriculture (LM) Cotton-Sorghum-Pigeonpea	P13	566	564	554	553
4.	Paral	Agriculture (HM) Cotton-Pigeonpea-Sorghum	P14	605	592	664	493
5.	Jajapura	Agriculture (FM I) Sorghum-Pigeonpea-Green gram	P35	138	123	105	101
6.	Jajapura	Agriculture (FM II) Paddy-Paddy	P36	375	312	224	180
7.	Kasireddi palli	Agriculture (HM) Soybean-Pigeonpea intercropping	P39	175	159	156	157
8.	Kasireddi palli	Agriculture (TM) Fallow-Bengal gram	P40	191	173	155	146
9.	Konheri	Agriculture (FM) PP/SF Fallow-Sorghum	P45	461	454	440	409
10.	Konheri	Agriculture (LM) Fallow-Sorghum	P46	347	344	316	283
11.	Kalwan	Agriculture (FM) Maize-Sugarcane/Onion/Wheat	P47	578	482	434	451
12.	Kovilpatti	Agriculture (original) Sorghum	P19	247	230	210	207
13.	Kovilpatti	Waste land	P20	223	203	203	210
14.	Kovilpatti	Agriculture (HM) Cotton	P21	351	308	250	303
15.	Semla	Agriculture (FM) Groundnut/Cotton	P29	417	365	292	262
16.	Teligi	Agriculture (LM) Paddy-Paddy	P43	379	316	260	240
17.	Teligi	Agriculture (HM) Paddy-Paddy	P44	448	472	291	264

The concentration of total P in 0–30 cm depth ranged from 138 mg kg^{-1} in Jajapur series (P35) to 605 mg kg^{-1} in Paral series (P14). The difference in P concentration in the above values in the two series can be attributed to the clay content. The clay content was 63% for P14 and 35% for P35. The low total P concentration in the Kasireddypalli series (175 mg kg^{-1}) was due to the transition of red and black soils wherein the parent material (PM) influence has to be investigated. There was considerable difference in TP concentration among Jajapur series P35 and P36. The soils of P35 are featured by upper piedmont areas, which might have resulted in low TP content while the soils of P36 are cultivated are considerably fertilized for paddy crop, which might have caused a considerable increase in TP content. The soils of Kovilpatti series were low in TP. There was no significant correlation of total P with the clay content among the soils of this zone. The TP also decreased with depth.

3.4.2.5 Arid

The total P concentration of black soils at various depths in arid zone is presented in Table 3.4.5.

Table 3.4.5. Profile distribution of total P concentration in black soils in various benchmark spots under arid zone.

				Total P (mg kg^{-1})			
				Soil depth (cm)			
Sl. no.	Series	System	P. no.	0–30	0–50	0–100	0–150
1.	Sokhda	Agriculture (FM I) Cotton/Pearl millet	P30	215	222	224	187
2.	Sokhda	Agriculture (FM II) Cotton-Pearl millet/Linseed	P31	143	141	147	150
3.	Nimone	Agriculture (HM) Cotton-Wheat/ Chickpea (Irrigated)	P51	484	460	434	418
4.	Nimone	Agriculture (FM) Sugarcane-Soybean/ Wheat/Chickpea	P52	426	412	391	370

The total P concentration in 0–30 cm depth varied between 143 mg kg^{-1} in Sokhda series (P31) to 484 mg kg^{-1} in Nimone series (P51), the variation being 238%. This considerable difference could be attributed to the clay and organic carbon content. The SOC and clay content were 0.5% and 31%, respectively, in case of P31, and 0.76% and 67%, respectively, in case of P51. Within Sokhda series, the difference in TP content could be attributed to the distance of PM from topsoil: soils of P30, the PM was around 80 cm from the soil surface, and the PM of P31 was found at higher depths (90–100 cm). Both PM and input levels were the reasons for the high content of TP in soils of Nimone series.

Red Soils

3.4.2.6 Sub-humid (moist)

The total P concentration of soils at various depths of red soils in sub-humid (moist) zone is presented in Table 3.4.6.

Table 3.4.6. Profile distribution of total P concentration in red soils in various benchmark spots under sub-humid (moist) zone.

				Total P (mg kg^{-1})			
				Soil depth (cm)			
Sl. no.	Series	System	P. no.	0–30	0–50	0–100	0–150
1.	Dadarghugri	Agriculture (LM) Maize-Mustard (Pigeonpea)	P23	1859	1797	1765	1744
2.	Dadarghugri	Forest system teak	P24	1140	1092	1057	1045
3.	Karkeli	Forest system sal	P25	270	256	232	230
4.	Karkeli	Agriculture (LM) Sweet potato/ Minor millet (kodo)	P26	147	158	163	161

The total P concentration in 0–30 cm depth varied from as low as 147 mg kg^{-1} in Karkeli series (P26) to as high as 1859 mg kg^{-1} in Dadarghugri series (P23). The difference in the above values can be attributed primarily to the parent material. The parent material was weathered basalt for the soils under Dadarghugri series, and weathered sandstone for soils under Karkeli series. This difference in the parent material coupled with other major soil properties such as clay, organic carbon content and the relief features explain the variation in the above series. The content of TP concentration decreased with depth.

3.4.2.7 Semi-arid (moist)

The total P concentration of soils in red soils semi-arid (moist) zone is presented in Table 3.4.7.

Table 3.4.7. Profile distribution of total P concentration in red soils in various benchmark spots under semi-arid (moist) zone.

				Total P (mg kg^{-1})			
				Soil depth (cm)			
Sl. no.	Series	System	P. no.	0–30	0–50	0–100	0–150
1.	Vijayapura	Agriculture (FM) Finger millet	P16	162	148	125	114
2.	Vijayapura	Agriculture (original) Pulses	P17	215	174	136	118
3.	Vijayapura	Agriculture (HM) Finger millet	P18	176	142	110	97

Vijayapura was the sole series in this zone. The total P concentration in the 0–30 cm depth varied from 162 mg kg^{-1} in P16 to 215 mg kg^{-1} in P17. The content of TP also decreased with depth.

3.4.2.8 Semi-arid (dry)

The total P concentration of red soils under semi-arid (dry) zone is presented in Table 3.4.8.

Table 3.4.8. Profile distribution of total P concentration in red soils in various benchmark locations under semi-arid (dry) zone.

Sl. no.	Series	System	P. no.	Total P (mg kg^{-1}) Soil depth (cm) 0–30	0–50	0–100	0–150
1.	Hayatnagar	Agriculture (HM) Sorghum-Castor	P37	213	204	320	401
2.	Hayatnagar	Agriculture (LM) Sorghum-Castor	P38	284	273	488	660
3.	Patancheru	Fallow system Permanent fallow grassland	P41	130	121	131	164
4.	Kaukuntla	Agriculture (FM) Castor+Pigeonpea	P34	170	142	110	96
5.	Palathurai	Horticulture (original) Tomato	P22	1158	1156	1157	1156

The total P content of 0–30 cm depth varied from 130 mg kg^{-1} in Patancheru series (P41) to 1158 mg kg^{-1} in Palathurai series (P22). The difference in P concentration could be due to the parent material. The mineralogy of soils in P22 needs investigation to explain the high P concentration in those soils. The pH of surface soils in Palathurai series is 7.7 as against 5.4 for the other series in this zone. Analysis of soil parameters such as clay, fine clay and organic carbon of the above two series revealed that P41 had high values for the above soil properties. The surface soils of Hayatnagar series were found low in TP content but there was an increase in P at higher depths due to the presence of calcium carbonate wherein the P could be bound and this resulted in high TP content. The low content of TP in soils of Patancheru series could be attributed to parent material with total phosphorus content.

3.4.3 Variation of total P concentration of soils under different land-use systems

The total P concentration in black soils at 0–30 cm depth under various land-uses for black and red soils are given in Figures. 3.4.13 and 3.4.14 respectively. The total P concentration in black soils was highest at 425 mg kg^{-1} under horticultural system and was closely followed by agricultural system with 373 mg kg^{-1} TP. The TP content in forest soils was the lowest at 152 mg kg^{-1}.

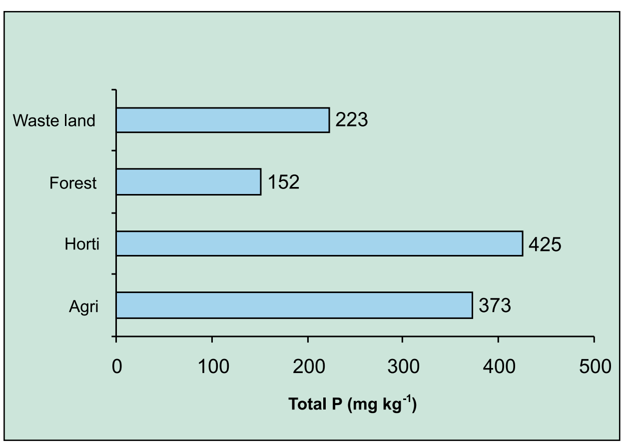


Figure 3.4.13. Total P in black soils at 0–30 cm depth in different land-use systems.

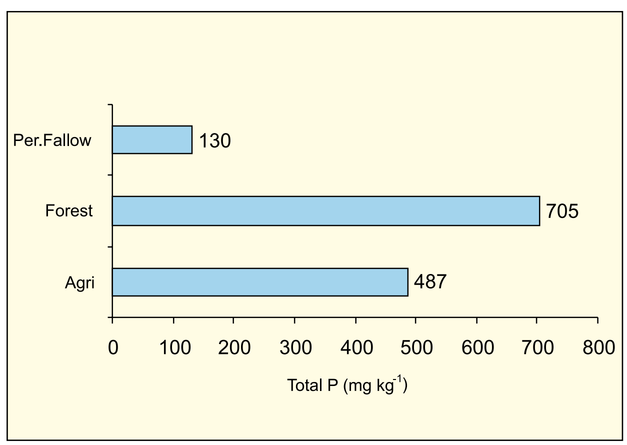


Figure 3.4.14. Total P in red soils at 0–30 cm depth in different land-use systems.

The carbon content of soils under forest was high among the various systems. Wasteland soils had a slightly higher content of total P as compared to those under forest system. Contrary to the results for black soils, the total P content in red soils at 0–30 cm depth was highest for forest systems, followed by soils under agricultural systems (Figure 3.4.14).

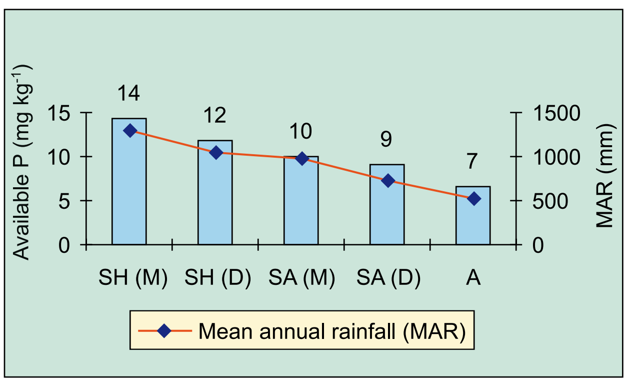
3.5 Available Phosphorus

Phosphorus deficiency is a widespread problem in India. Available P in soils of India is low or medium in 98% of the districts, and they need moderate doses of phosphorus application for higher yield (Ghosh and Hassan 1979). The available phosphorus in soil is low in relation to total P, and is about 0.1 mg kg^{-1}. However, routine soil tests for P do not analyze for the total P content because the amount of soil P in plant available forms is always much less than the total P. In this context, the available phosphorus analysis will be of much help to plan suitable crop(s), to improve yield and below-ground biomass and thus to add more organic carbon content in soils. The variability in available P content of soils under different bioclimatic zones, benchmark spots and land-uses are discussed in this section.

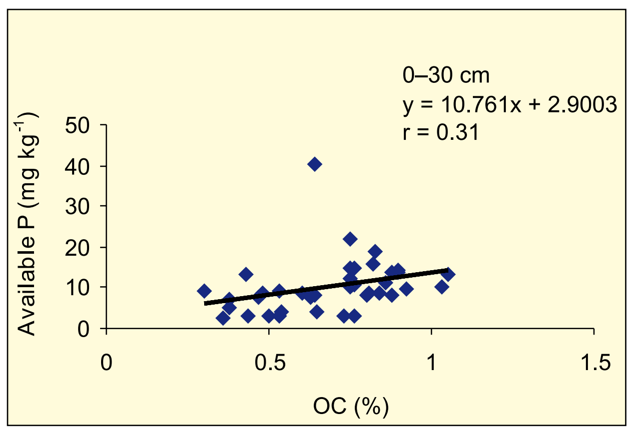
3.5.1 Variation in available P in different bioclimatic zones

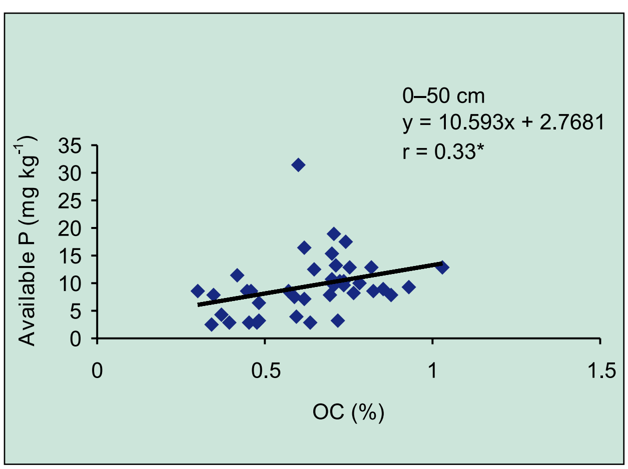
3.5.1.1 Black soils

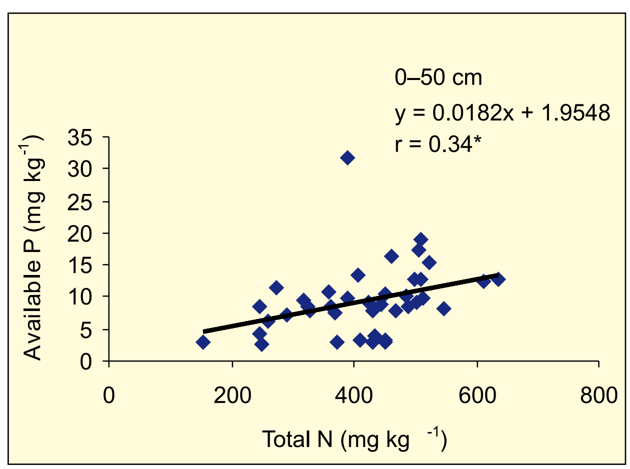
The distribution of available P in 0–30 cm depth in various bioclimatic zones is given in Figure 3.5.1.



Figures 3.5.1. Available phosphorus content of black soils in different bioclimatic systems.





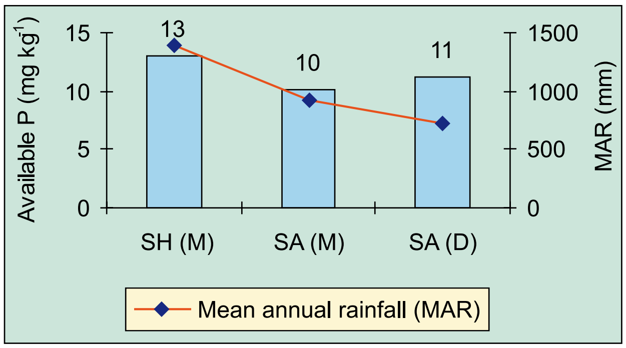


Figures 3.5.2 to 3.5.4. Relationship of various parameters with available P in black soils at different depths.

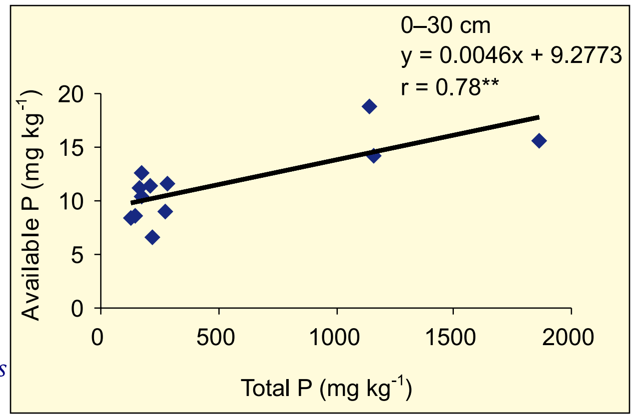
With the decrease in the rainfall, the available P content also decreased and was lowest in arid zone. As organic carbon of soils also contains a considerable portion of phosphorus, the available P content of black soils was positively but insignificantly correlated with this parameter (Figure 3.5.2). The relationship of available P with other parameters such as organic carbon and total N in soils at higher depths was positive and significant (Figures. 3.5.3 and 3.5.4).

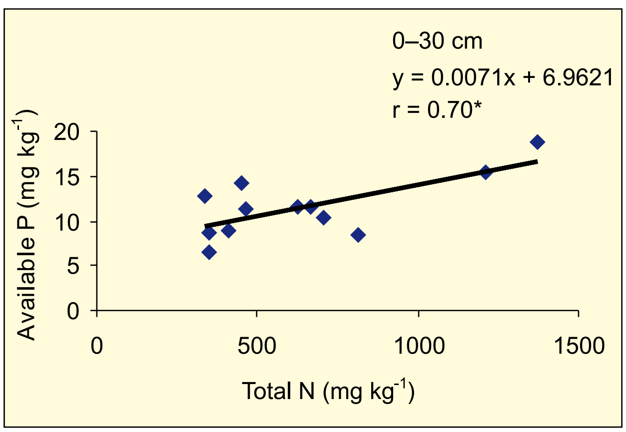
3.5.1.2 Red soils

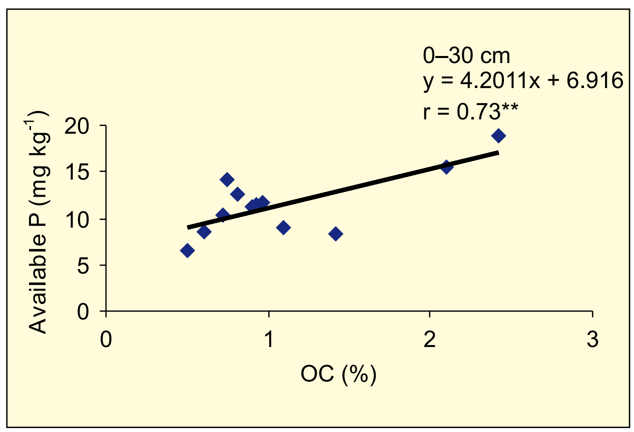
The variations in available P content in 0–30 cm depth under different bioclimatic zones are given in Figure 3.5.5. As in black soils, the content of available P also decreased with decrease in the rainfall and was more or less similar for soils in semi-arid (moist) and semi-arid (dry) zones. The content of available P was also highly correlated with total P, total N, organic carbon and clay content in various depths (Figures 3.5.6 and 3.5.11).

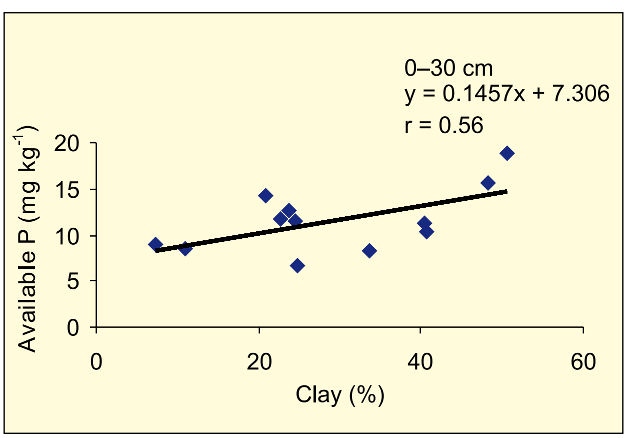


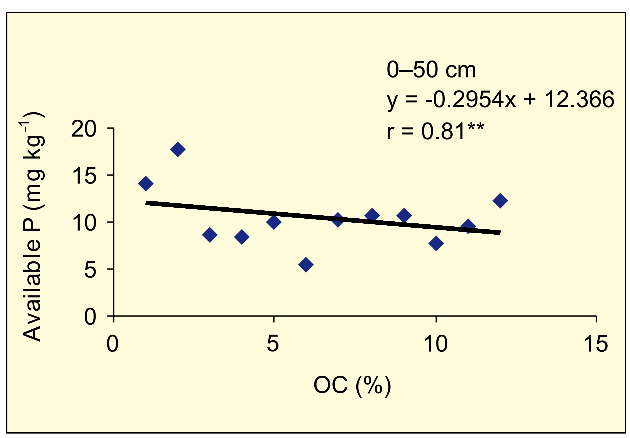
Figures 3.5.5. Available phosphorus content of red soils in different bioclimatic regions.

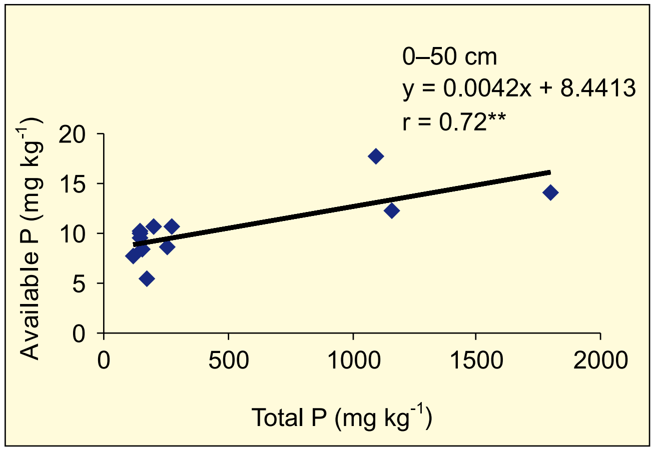












Figures 3.5.6. to 3.5.11 Relationship of various parameters with available P in red soils at different depths.

3.5.2 Variation in available P in different benchmark locations

Black Soils

3.5.2.1 Sub-humid (moist)

Variation in available P content of black soils in different benchmark spots under sub-humid (moist) zone is given in Table 3.5.1.

Table 3.5.1. Profile distribution of available P concentration in various benchmark locations of black soils under sub-humid (moist) zone.

				Avail. P (mg kg^{-1})			
				Soil depth (cm)			
Sl. no.	Series	System	P. no.	0–30	0–50	0–100	0–150
1	Kheri	Agriculture (HM) Rice/Wheat/Maize	P27	9	9	7	7
2	Kheri	Agriculture (FM) Soybean-Wheat	P28	8	8	7	7
3	Boripani	Reserve forest teak	P15	9	8	7	7
4	Nabibagh	Agriculture (HM) Soybean-Wheat	P5	15	13	10	8
5	Nabibagh	Agriculture (FM) Soybean-Wheat, Gram	P6	4	4	3	2
6	Panjri	Agriculture (HM) Cotton	P4	40	32	22	18

Available P content varied between 4 mg kg^{-1} in the soils of Nabibagh series (P6) to 40 mg kg^{-1} in the soils of Panjri series (P4). The well-marked difference in the available P content between the two series could be due to the variations in the clay content, which was 49% in soils P6 and 57% in P4. The fine-clay content in the above benchmark spots also showed a considerable difference; it was 32% in 0–30 cm for P6 and 46% for P4.

3.5.2.2 Sub-humid (dry)

Available P content of soils in different benchmark spots of sub-humid (dry) is presented in Table 3.5.2.

Table 3.5.2. Profile distribution of available P in various benchmark spots of black soils under sub-humid (dry) zone.

Sl. no.	Series	System	P. no.	Avail. P (mg kg^{-1}) Soil depth (cm) 0–30	0–50	0–100	0–150
1	Nipani	Agriculture (FM) Cotton+Pigeonpea & alternative Sorghum & Maize	P48	16	15	14	13
2	Pangidi	Agriculture (FM) Soybean+Pigeonpea	P49	13	13	12	11
3	Pangidi	Agriculture Soybean	P50	14	13	10	10
4	Sarol	Agriculture (HM) Soybean-Wheat	P7	4	3	3	
5	Sarol	Agriculture (FM) Soybean-Wheat	P8	3	3	3	3
6	Sarol	Agriculture (HM) Soybean-Gram	P9	3	3	3	2
7	Linga	Horticulture (HM) Orange	P1	22	19	14	10
8	Linga	Horticulture (LM) Orange	P3	11	10	7	5
9	Linga	Agriculture (FM) Soybean-Gram/Wheat	P2	19	17	15	13

The available P content in soils of different benchmark spots ranged from 3 mg kg^{-1} in Sarol series (P8 and P9) to 22 mg kg^{-1} in Linga series (P1). The variation could be attributed to the total P and clay fractions in the two zones. Accordingly, the total P and clay content for P9 and P1 were 325 mg kg^{-1} and 59%, and 423 mg kg^{-1} and 67% respectively. Among the Linga series the high-management horticultural system had the highest available P whereas low-management system was found to contain 11 mg kg^{-1} of available P.

3.5.2.3 Semi-arid (moist)

Available P content of soils in different benchmark spots of semi-arid (moist) is presented in Table 3.5.3.

Table 3.5.3. Profile distribution of available P in various benchmark spots of black soils under semi-arid (moist) zone.

Sl. no.	Series	System	P. no.	Avail. P (mg kg^{-1}) Soil depth (cm) 0–30	0–50	0–100	0–150
1	Bhatumbra	Agriculture (FM) S+PP/ Black gram-Chickpea	P42	8	8	7	7
2	Asra	Agriculture (FM) Cotton-GG-PP intercropping Cotton/PP	P10	10	10	8	7
3	Asra	Agriculture (FM) SB-PP intercropping Soy/PP	P11	12	11	9	8
4	Asra	Agriculture (HM) Soybean-Gram-Cotton-Pigeonpea	P12	10	9	8	7

The available P varied between 8 to 12 mg kg^{-1} among the benchmark spots covered in Bhatumbra and Asra. No significant variations in the content of available P was observed among the benchmark spots in this zone.

3.5.2.4 Semi-arid (dry)

Variations in available P content of soils in different benchmark spots of semi-arid (dry) are presented in Table 3.5.4.

Table 3.5.4. Profile distribution of available P in various benchmark spots of black soils under semi-arid (dry) zone.

				Avail. P (mg kg^{-1})			
				Soil depth (cm)			
Sl. no.	Series	System	P. no.	0–30	0–50	0–100	0–150
1	Jhalipura	Agriculture (FM) Soybean-Wheat	P32	3	3	2	2
2	Jhalipura	Agriculture (FM II)Paddy-Wheat	P33	3	3	2	2
3	Paral	Agriculture (LM) Cotton-Sorghum-Pigeonpea	P13	8	7	7	6
4	Paral	Agriculture (HM) Cotton-Pigeonpea-Sorghum	P14	9	9	8	7
5	Jajapur	Agriculture (FM I) Sorghum-Pigeonpea-Green gram	P35	7	8	8	7
6	Jajapur	Agriculture (FM II) Paddy-Paddy	P36	14	12	11	10
7	Kasireddi palli	Agriculture (HM) Soybean-Pigeonpea intercropping	P39	15	16	13	11
8	Kasireddi palli	Agriculture (TM) Fallow-Gram	P40	9	9	8	8
9	Konheri	Agriculture (FM) Pigeonpea/Sunflower Fallow-Sorghum	P45	9	9	8	7
10	Konheri	Agriculture (LM) Fallow-Sorghum	P46	9	9	7	7
11	Kalwan	Agriculture (FM) Maize-Sugarcane/Onion/Wheat	P47	14	13	12	11
12	Kovilpatti	Agriculture (original) Sorghum	P19	5	4	3	3
13	Kovilpatti	Wasteland	P20	8	6	5	4
14	Kovilpatti	Agriculture (HM) Cotton	P21	13	11	9	7
15	Semla	Agriculture (FM) Groundnut/Cotton	P29	11	10	9	8
16	Teligi	Agriculture (LM) Paddy-Paddy	P43	10	9	8	7
17	Teligi	Agriculture (HM) Paddy-Paddy	P44	8	8	7	7

The available P varied between 3 mg kg^{-1} in Jhalipura series (P32 and P33) and 15 mg kg^{-1} in Kasireddipalli series (P39). The variation in the above series was distinct due to the large difference in the amount of organic carbon (0.44% for P32 and 0.76% for P39). Moreover, the available P content was significantly correlated with the organic carbon content in the 0–30 cm layer (Figure 3.5.12) and positively correlated at higher depths (Figure 3.5.13). At still higher depths (0-100 cm), the available P was significantly correlated with total N (Figure 3.5.14).

3.5.2.5 Arid

Available soil P in different benchmark spots of arid zone soils is presented in Table 3.5.5.

Table 3.5.5. Profile distribution of available P in various benchmark spots of black soils under arid zone.

				Avail. P (mg kg^{-1})			
				Soil depth (cm)			
Sl. no.	Series	System	P. no.	0–30	0–50	0–100	0–150
1.	Sokhda	Agriculture (FM I) Cotton/Pearl millet	P30	3	3	2	2
2.	Sokhda	Agriculture (FM II) Cotton-Pearl millet-Linseed	P31	3	3	3	2
3.	Nimone	Agriculture (HM) Cotton-Wheat/ Chickpea (Irrigated)	P51	11	10	10	9
4.	Nimone	Agriculture (FM) Sugarcane-Soybean/ Wheat/Chickpea	P52	11	10	9	9

The available P content of soils among the various benchmark spots of arid zone varied between 3 mg kg^{-1} in Sokhda series (P30 and P31) and 11 mg kg^{-1} in Nimone series (P51 and P52). The available P content was positively and significantly correlated with organic carbon, total P, fine clay and available S, especially at 0–30 cm depth (Figures. 3.5.15 to 3.5.18).

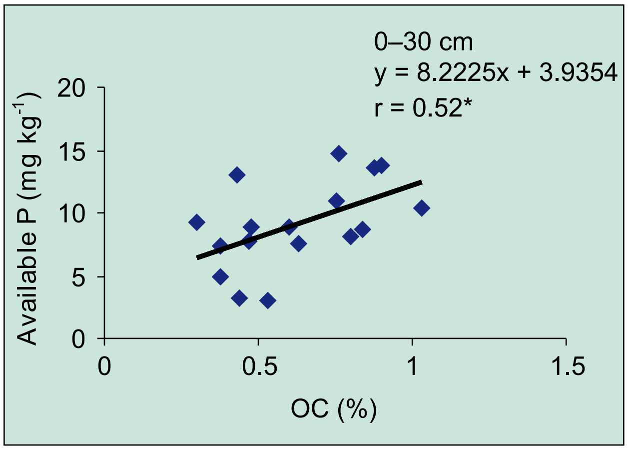
***Red Soil*s**

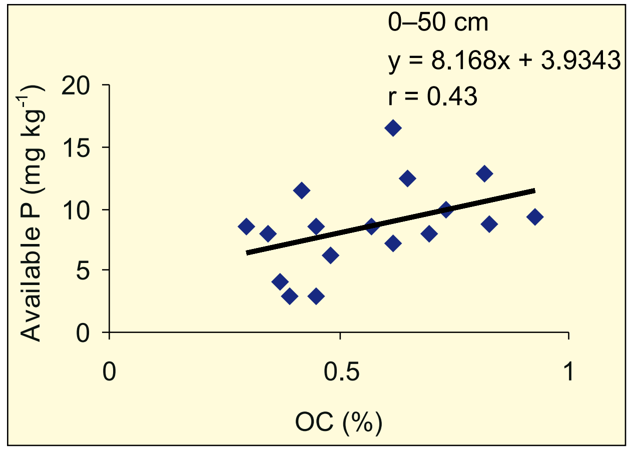
3.5.2.6 Sub-humid (moist)

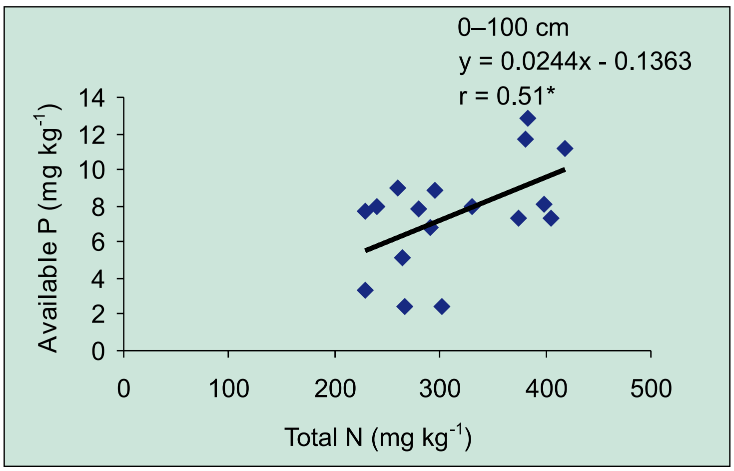
Available soil P in different benchmark spots of sub-humid (moist) zone is presented in Table 3.5.6.

Table 3.5.6. Profile distribution of available P in various benchmark spots of red soils under sub-humid (moist) zone.

				Avail. P (mg kg^{-1})			
				Soil depth (cm)			
Sl. no.	Series	System	P. no.	0–30	0–50	0–100	0–150
1.	Dadarghugri	Agriculture (LM) Maize-Mustard (Pigeonpea)	P23	16	14	13	13
2.	Dadarghugri	Forest system teak	P24	19	18	17	17
3.	Karkeli	Forest system sal	P25	9	9	8	8
4.	Karkeli	Agriculture (LM) Sweet potato/ Minor millet (kodo)	P26	9	8	8	7







Figures 3.5.12 to 3.5.14. Relationship of available P with different soil parameters at various depths in black soils under semi-arid (dry) zone.

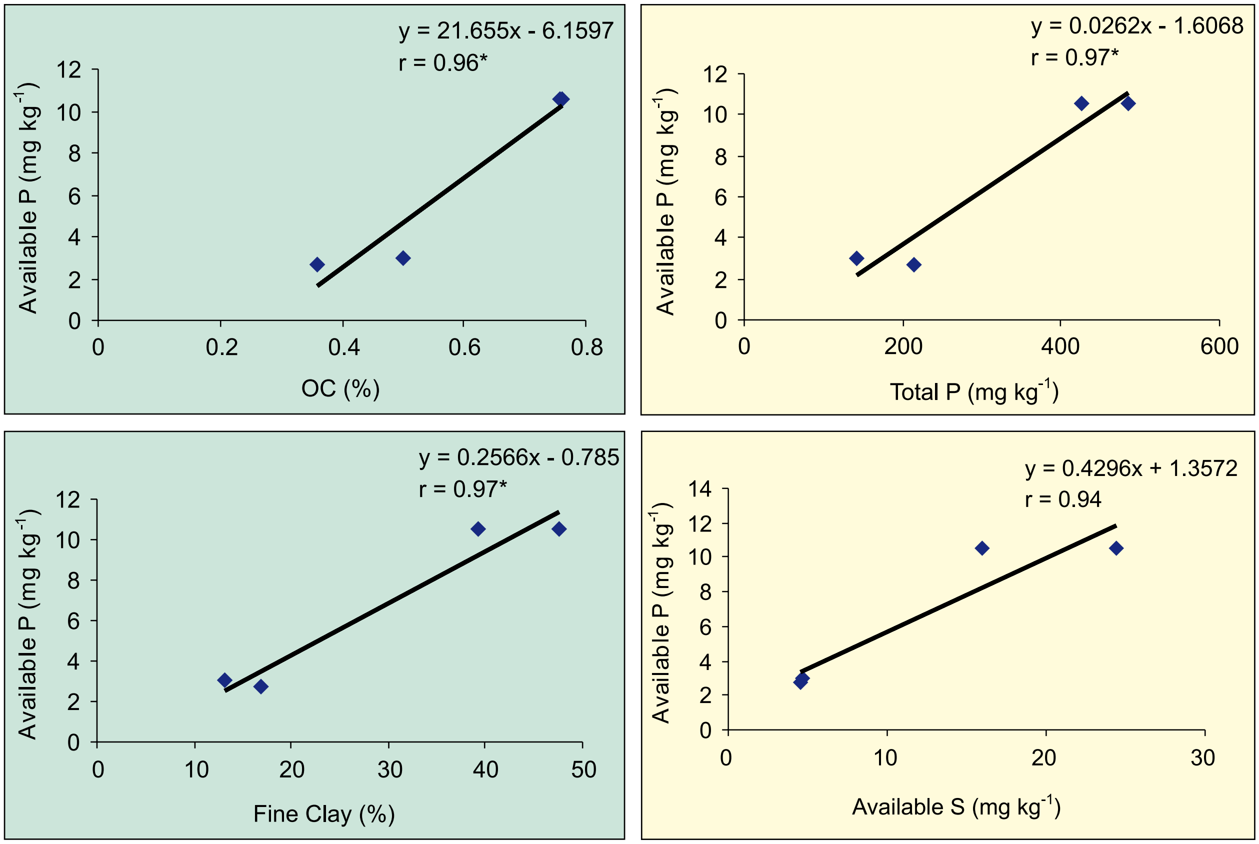
The available P in soils in this zone varied widely among the benchmark spots, and it was lowest in the soils of Karkeli series (P25 and P26) at 9 mg kg^{-1} and highest in the soils of Dadarghugri series (P24) with 19 mg kg^{-1}.

3.5.2.7 Semi-arid (moist)

Available P content of red soils in different benchmark spots of semi-arid (moist) zone are presented in Table 3.5.7.

Table 3.5.7. Profile distribution of available P in various benchmark spots of red soils under semi-arid (moist) zone.

				Avail. P (mg kg^{-1}) Soil depth (cm)			
Sl. no.	Series	System	P. no.	0–30	0–50	0–100	0–150
1.	Vijayapura	Agriculture (FM) Finger millet	P16	11	10	8	6
2.	Vijayapura	Agriculture (original) Pulses	P17	7	5	5	4
3.	Vijayapura	Agriculture (HM) Finger millet	P18	13	10	7	6



Figures 3.5.15 to 3.5.18. Relationship of available P with different soil parameters at 0–30 cm depth in black soils under arid zone.

The available P varied from 7 to 13 mg kg^{-1} of soil in the sole series of Vijayapura in this zone. The reasons for the above variations can be primarily attributed to the varying content of organic carbon within the series. The available P is negatively correlated with total P.

3.5.2.8 Semi-arid (dry)

Variations in available P content of soils in different benchmark spots of semi-arid (dry) are presented in Table 3.5.8.

Table 3.5.8. Profile distribution of available P in various benchmark spots of red soils in semi-arid (dry) zone

				Avail. P (mg kg^{-1})			
				Soil depth (cm)			
Sl. no.	Series	System	P. no.	0–30	0–50	0–100	0–150
1	Hayatnagar	Agriculture (HM) Sorghum-Castor	P37	11	11	10	10
2	Hayatnagar	Agriculture (LM) Sorghum-Castor	P38	12	11	9	9
3	Patancheru	Fallow system Permanent Fallow Grass land	P41	8	8	7	10
4	Kaukuntla	Agriculture (FM) Castor+Pigeonpea	P34	10	9	8	7
5	Palathurai	Horticulture (original) Tomato	P22	14	12	10	9

Available P varied between 8 mg kg^{-1} in Patancheru series (P41) and 14 mg kg^{-1} in Palathurai series (P22). The available P content was positively correlated with total P and it was clear from the high value of available P in P22, which also contained the highest value of total P in this zone. However, the organic carbon content was negatively correlated with the available P.

3.5.3 Variation of available P under different land-use systems

The available P content of soils under different types of land-use is given in Figures 3.5.19 for black soils and 3.5.20 for red soils. It was observed that the black soils under horticultural systems were found to have highest available P content. The red soils under forest system had maximum concentration of available P as compared to agricultural and fallow systems.

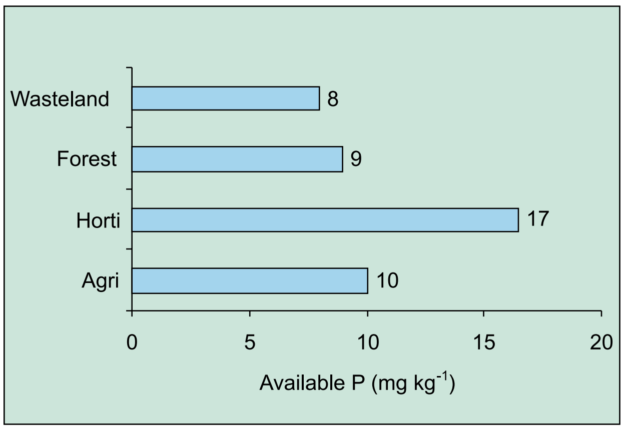


Figure 3.5.19. Variations in available P content of black soils under different land-use systems.

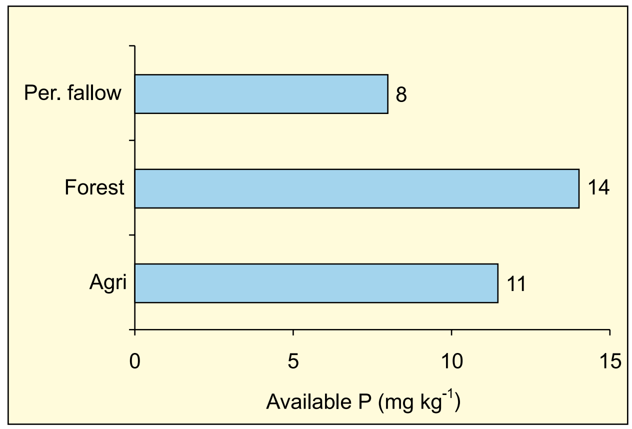


Figure 3.5.20. Variations in available P content of red soils under different land-use systems.

3.6 Phosphorus stocks

3.6.1 Total and available P stocks in different bioclimatic zones

3.6.1.1 Black soils

The variations in the amount of total phosphorus and available phosphorus stocks at 0–30 cm depths in various bioclimatic zones are given in Figures 3.6.1 and 3.6.2. The trend of phosphorus stocks in different bioclimatic zones was similar to that of nutrient content under black soils.

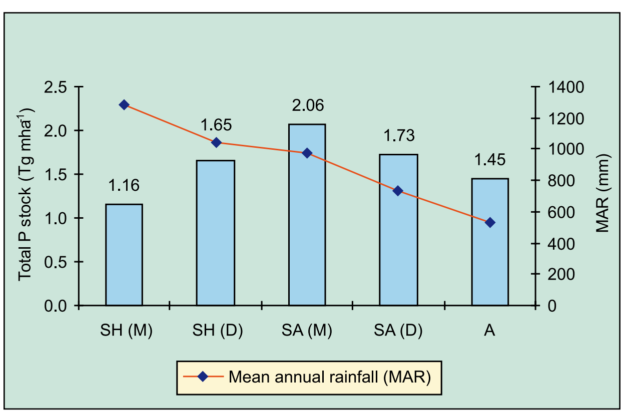


Figure 3.6.1. Total phosphorus stocks of black soils at 0–30 cm depth in different bioclimatic zones.

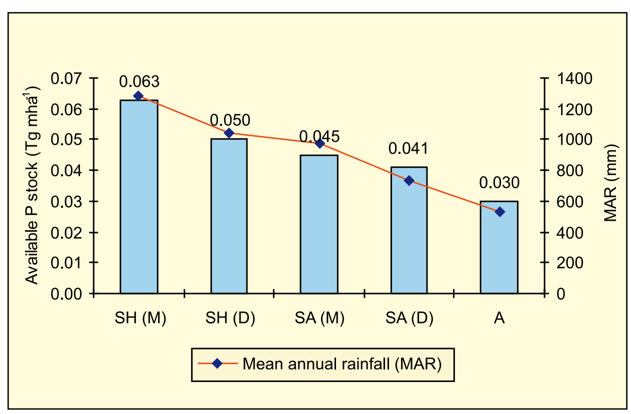


Figure 3.6.2. Available phosphorus stocks of black soils at 0–30 cm depth in different bioclimatic zones.

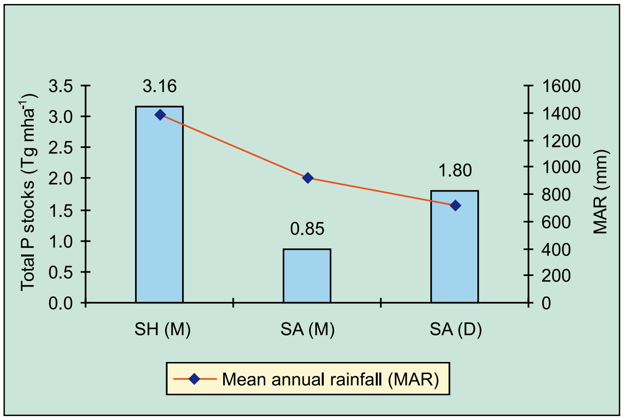


Figure 3.6.3. Total phosphorus stocks of red soils at 0–30 cm depth in different bioclimatic zones

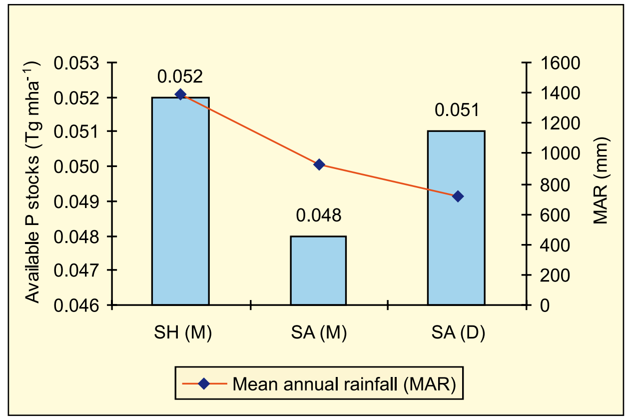


Figure 3.6.4. Available phosphorus stocks of red soils at 0–30 cm depth in different bioclimatic zones

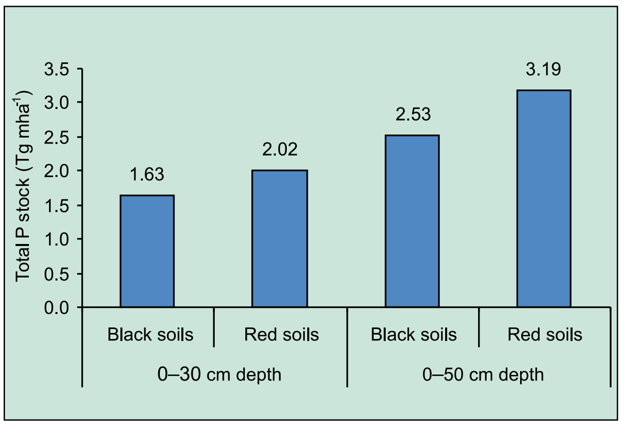


Figure 3.6.5. Total P stocks in various depths of black and red soils

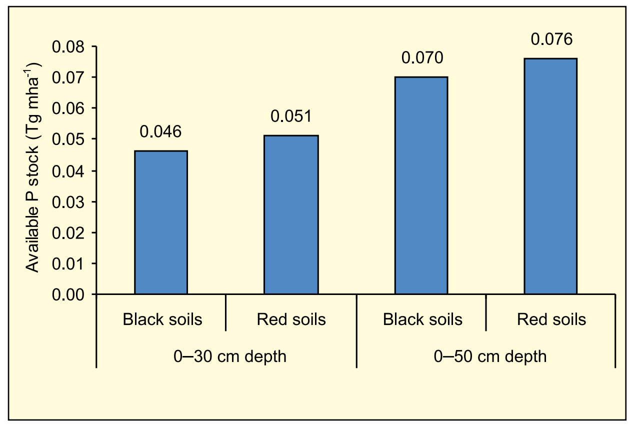


Figure 3.6.6. Available P stocks of black and red soils in various depths

3.6.1.2 Red soils

Total and available phosphorus stocks in 0–30 cm depth in red soils in different bioclimatic zones are given in Figures 3.6.3 and 3.6.4 respectively. Similar to black soils, the phosphorus stocks in red soils had the same trend as that of content in various bioclimatic zones.

3.6.2 Total and available P stocks in different benchmark spots

Black Soils

3.6.2.1 Sub-humid (moist)

Total P and available P stocks in black soils in 0–30 cm depth are given in Table 3.6.1. Total P and available P stocks ranged from 0.99 to 1.72 and 0.02 to 0.19 Tg mha^{-1}, respectively. Agricultural system with high-management levels under paddy-wheat rotation (P27) showed 89.2% higher levels of total P stocks than series with lowest stocks (P15). The distribution of total P stocks of major soils series among sub-humid (moist) zone is illustrated in Figure 3.6.7.

Table 3.6.1. Total P and available P stocks in black soils of sub-humid (moist) zone in SAT, India.

Pedon no.	Series	Systems (crop)	Total P stock (Tg/mha^{-1}) Soil depth (cm) 0–30	0–50	0–100	0–150	Avail. P stock (Tg/mha^{-1}) Soil depth (cm) 0–30	0–50	0–100	0–150
P27	Kheri	AS (HM) Rice/ Wheat/Maize	1.72	2.45	3.98	5.98	0.04	0.06	0.11	0.17
P28	Kheri	AS (FM) Soybean-Wheat	0.95	1.48	2.93	4.55	0.03	0.05	0.10	0.14
P15	Boripani	Reserve forest teak	0.62	1.04	4.63	8.79	0.04	0.06	0.10	0.13
P5	Nabibagh	AS (HM) Soybean-Wheat	1.31	2.00	3.89	5.91	0.06	0.09	0.14	0.15
P6	Nabibagh	AS (FM) SB-W, G	1.38	2.30	4.77	7.08	0.02	0.03	0.04	0.05
P4	Panjri	AS (HM) Cotton	0.99	1.57	3.01	4.22	0.19	0.24	0.33	0.41

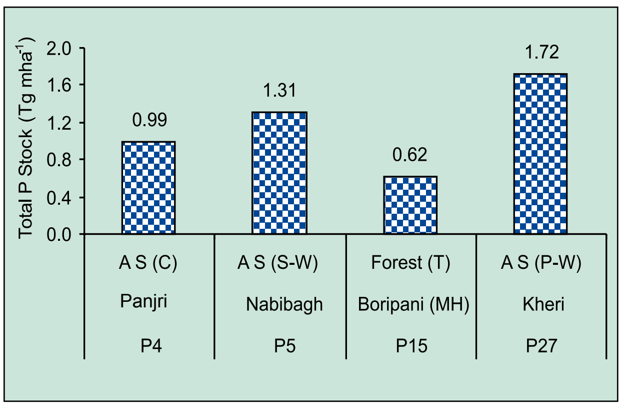


Figure 3.6.7 Total P stocks in sub-humid (moist) bioclimatic zone (0–30 cm) in black soils.

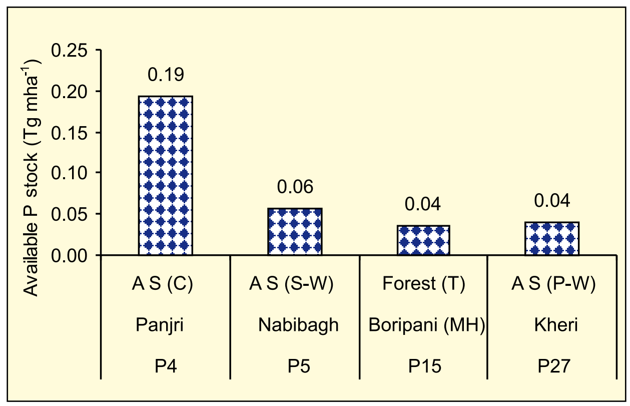


Figure 3.6.8 Available P stocks in sub-humid (moist) bioclimatic zone (0–30 cm) in black soils

Available P stock showed a different trend compared to total P stock. High available P stock was found in Panjri series (0.19 Tg mha^{-1}), which was under high-management cotton cultivation (Figure 3.6.8).

Red Soils

Data on total and available P stocks of red soils are given in Table 3.6.2. The total and available P stocks ranged from 0.75 to 6.8 Tg mha^{-1} and 0.04 to 0.06 Tg mha^{-1}, respectively. High total P stock was observed in maize-mustard cropping system under farmers' management and high available P stock was observed in forest system. There was 1.6 times higher total P under teak forest than under sal forest (Figure 3.6.9), and there was 0.29 times higher levels of available P soil stocks in teak forests than sal forests (Figure 3.6.10). This indicates that in this zone, higher P levels are found in forest system and in land under farmers' management. The results also indicated that in the same soil series and under same land-use system, the total and available P stocks varied because of variations in the cropping, soil organic and inorganic carbon levels, favorable pH and other conditions. Variation in total P stocks with soil depth is given in Figure 3.6.11. There was 1.07 times increase of total P stocks from 0–30 cm depth (1.43 Tg mha^{-1}) to 0–150 cm depth (2.97 Tg mha^{-1}) indicating that higher levels of stocks exist under lower depths (0–100 cm and 0–150 cm depths) (Figure 3.6.11).

Table 3.6.2. Total P and available P stocks in red soils of sub-humid moist zone.

Pedon no.	Series	Systems (crop)	Total P stock (Tg/mha-1) Soil depth (cm) 0–30	0–50	0–100	0–150	Avail. P stock (Tg/mha-1) Soil depth (cm) 0–30	0–50	0–100	0–150
P23	Dadarghugri	AS (LM) Maize-Mustard (Pigeonpea)	6.80	10.68	21.00	31.21	0.06	0.08	0.16	0.23
P24	Dadarghugri	forest system Teak	3.69	6.06	11.89	17.13	0.06	0.10	0.19	0.28
P25	Karkeli	Forest system sal	1.40	2.20	3.83	5.62	0.05	0.08	0.14	0.19
P26	Karkeli	AS (LM) SP/MM (kodo)	0.75	1.28	2.52	3.69	0.04	0.07	0.12	0.17

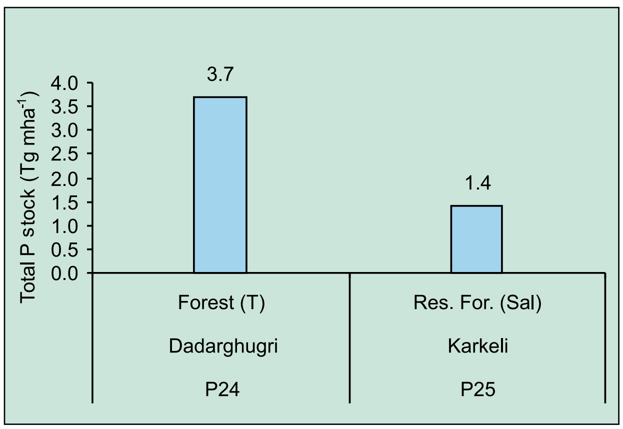


Figure 3.6.9. Total P stock in sub-humid (moist) bioclimatic zone (0–30 cm) in red soils.

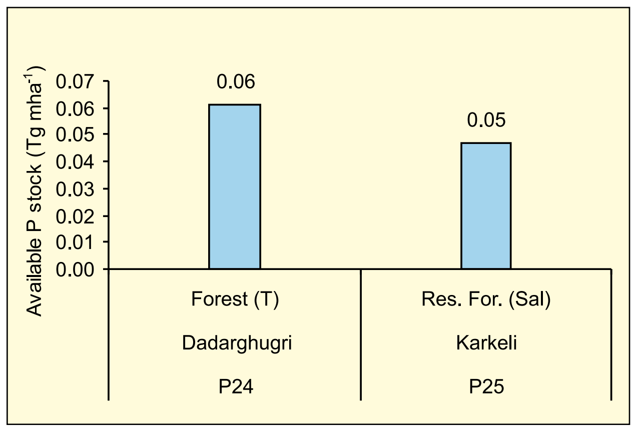


Figure 3.6.10. Available P stock in sub-humid (moist) bioclimatic zone (0–30 cm) in red soils.

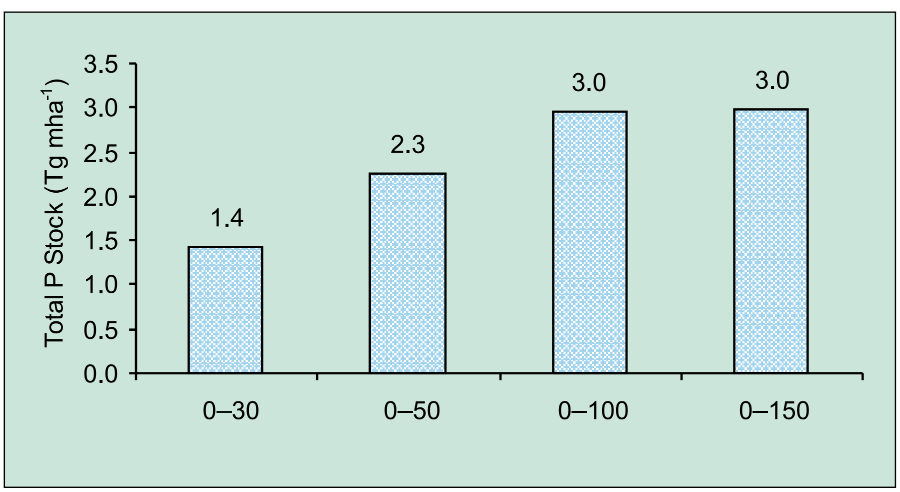


Figure 3.6.11. Variation in total P stocks under different depth ranges in red soils.

3.6.2.2 Sub-humid (dry)

Black Soils

The data on total and available P stocks of black soils at various depths are given in Table 3.6.3. The total and available P stocks at 0–30 cm depth ranged from 1.2 (P49) to 3.0 (P48) Tg mha^{-1} and 0.01 (P9) to 0.10 Tg mha^{-1} (P1), respectively. Nipani series (P48) under agricultural system with farmers' management and Linga series under horticultural system were observed to have highest content of total P and available P stocks, respectively (Figures 3.6.12 and 3.6.13). Nipani series (P48) under farmers' management recorded 58% higher total P stocks than highly managed horticultural system in Linga series (P1), whereas P2 recorded 30.6% higher levels of available P stock than P48. From the above figure, it was also observed that within the agricultural system, the soil in cotton-based system was found to have two times higher P stocks than those under soybean based system. The horticulture system was found to contain high stocks of available P (Figure 3.6.13).

Table 3.6.3. Total P and available P stocks in black soils of sub-humid (dry) zone in SAT, India.

Pedon no.	Series	Systems (crop)	Total P stock (Tg/mha^{-1}) Soil depth (cm) 0–30	0–50	0–100	0–150	Avail. P stock (Tg/mha^{-1}) Soil depth (cm) 0–30	0–50	0–100	0–150
P48	Nipani	AS (FM) C+PP & alternative Sorghum & Maize	3.00	4.24	7.46	11.12	0.08	0.12	0.21	0.29
P49	Pangidi	AS (FM) Soybean+ Pigeonpea	1.20	1.86	3.31	4.57	0.05	0.07	0.14	0.20
P50	Pangidi	AS (ITDA)Soybean	1.52	3.12	8.35	13.57	0.06	0.08	0.14	0.19
P7	Sarol	AS (HM) Soybean-Wheat	1.50	2.15	3.80	5.39	0.02	0.02	0.04	0.05
P8	Sarol	AS (FM) Soybean-Wheat	1.26	2.04	4.00	5.75	0.01	0.02	0.04	0.06
P9	Sarol	AS (HM)Soybean-Gram	1.37	2.11	3.88	6.01	0.01	0.02	0.04	0.05
P1	Linga	Horticulture (HM) Orange	1.90	2.83	4.62	6.44	0.10	0.14	0.19	0.21
P3	Linga	Horticulture (LM) Orange	1.79	2.71	4.90	7.00	0.05	0.07	0.10	0.12
P2	Linga	AS (FM) Soybean-Gram/ Wheat	1.33	2.09	3.77	5.62	0.08	0.13	0.22	0.29

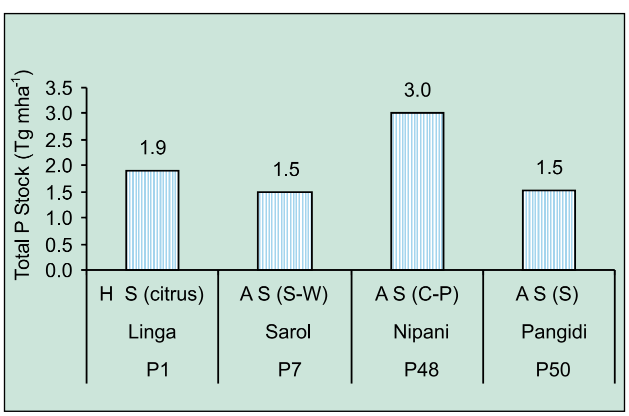


Figure 3.6.12 Total P stocks in sub-humid (dry) bioclimatic zone (0–30 cm) in black soils.

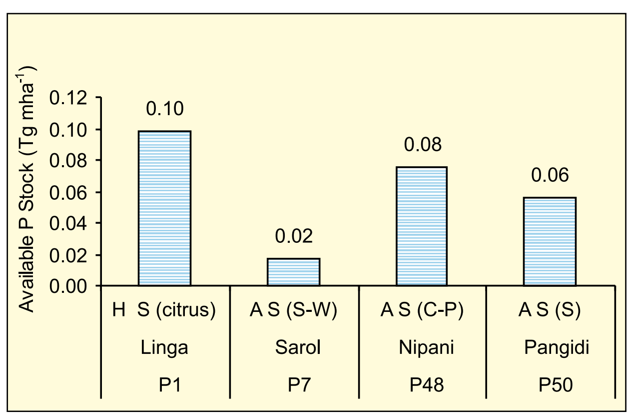


Figure 3.6.13 Available P stocks in sub-humid (dry) bioclimatic zone (0–30 cm) in black soils.

3.6.2.3 Semi-arid (moist)

Black Soils

Data on total and available P stocks of black soils at various depths are given in Table 3.6.4. Asra series had larger stocks (total and available P) under farmers' management than Bhatumbra series (Figures. 3.6.14 and 3.6.15). Agricultural system with farmers' management (P10 and P11) recorded 29.7% higher levels of total P stocks and 27.9% higher levels of available P stock than agricultural system with high-management (P12). Generally, in the series, the trends followed were from 1.78 to 2.39 Tg mha^{-1} and 0.03 to 0.05 Tg mha^{-1} of total and available P stocks, respectively.

Table 3.6.4 Total P and available P stocks in black soils of semi-arid (moist) zone in SAT, India.

			Total P stock (Tg/mha^{-1})				Avail. P stock (Tg/mha^{-1})			
			Soil depth (cm)				Soil depth (cm)			
Pedon no.	Series	Systems (crop)	0–30	0–50	0–100	0–150	0–30	0–50	0–100	0–150
P42	Bhatumbra	AS (FM) S+PP/Black gram-Chickpea	1.77	2.54	3.98	4.97	0.03	0.05	0.10	0.14
P10	Asra	AS (FM) CO-Green gram-PP IC CO/PP	2.39	3.98	7.56	11.12	0.05	0.08	0.13	0.17
P11	Asra	AS (FM) Soybean- PP IC SB/PP	2.32	3.72	7.38	11.12	0.05	0.08	0.14	0.19
P12	Asra	AS (HM) Soybean-Gram-CO-PP	1.78	2.79	5.13	7.63	0.04	0.07	0.12	0.16

The amount of TP and AP stocks were highest in soils of Asra series (P10) and lowest in soils of Bhatumbra series (P42). As the farmers' management of Asra series was high-level management, the P stocks were also found high as compared to the low-level farmers management of P42.

Red Soils

Data on total and available P stocks of soils at various depths are given in Table 3.6.5. Total P and available P at 0–30 cm depth ranged from 0.80 to 0.95 Tg mha^{-1} and 0.03 to 0.06 Tg mha^{-1} respectively. In Vijayapura series farmers' management (P16) and high-management (P18) systems maintained similar available P and total P stocks.

Table 3.6.5. Total P and available P stocks in red soils of semi-arid (moist) zone in SAT, India.

			Total P stock (Tg/mha^{-1})				Avail. P stock (Tg/mha^{-1})			
			Soil depth (cm)				Soil depth (cm)			
Pedon no.	Series	Systems (crop)	0–30	0–50	0–100	0–150	0–30	0–50	0–100	0–150
P16	Vijayapura	AS (FM) finger millet	0.81	1.21	1.99	2.67	0.06	0.08	0.13	0.15
P17	Vijayapura	AS (original) Pulses	0.95	1.23	1.86	2.41	0.03	0.04	0.07	0.08
P18	Vijayapura	AS (HM) finger millet	0.80	1.05	1.58	2.04	0.06	0.07	0.11	0.13

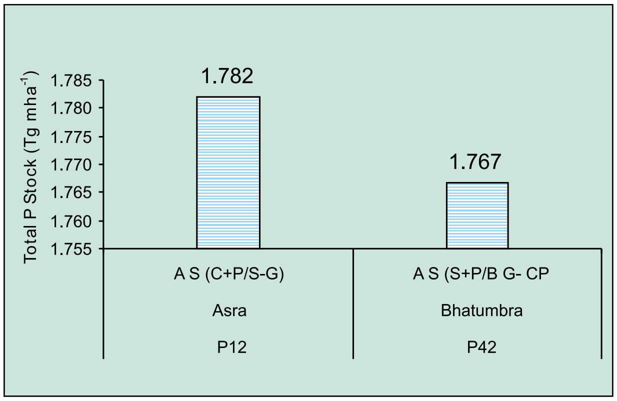


Figure 3.6.14. Total P stocks in semi-arid (moist) bioclimatic zone (0–30 cm) in black soils.

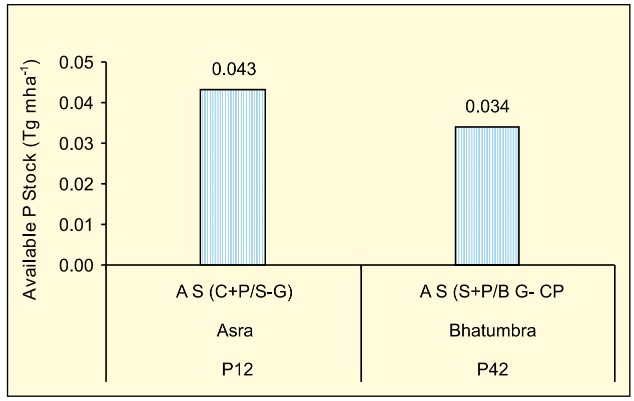


Figure 3.6.15. Available P stocks in semi-arid (moist) bioclimatic zone (0–30 cm) in black soils.

3.6.2.4 Semi-arid (dry)

Black Soils

Data in Table 3.6.6 and figures 3.6.16 and 3.6.17 show total and available P stocks in black soils of semi-arid (dry) zone. The values of total and available P stocks at 0–30 cm depth ranged between 0.75 in soils of Jajapur series (P35) and 2.90 Tg mha^{-1} (P14), and from 0.02 (P33) to 0.008 Tg mha^{-1} (P36), respectively. Highest total P and available P were recorded in agricultural system under farmers' management. The total P stocks were found to be the same for P32 and P47 (Figure 3.6.16), which were under farmers' management. Higher available P was also found in P32 and P47. (Figure 3.6.17). The higher P levels for both total and available were observed under farmers' management; and Jajapur series (P36) had 9.8 times higher available P and 1.5 times higher total P stocks than HM of Kasireddipalli series (P39).

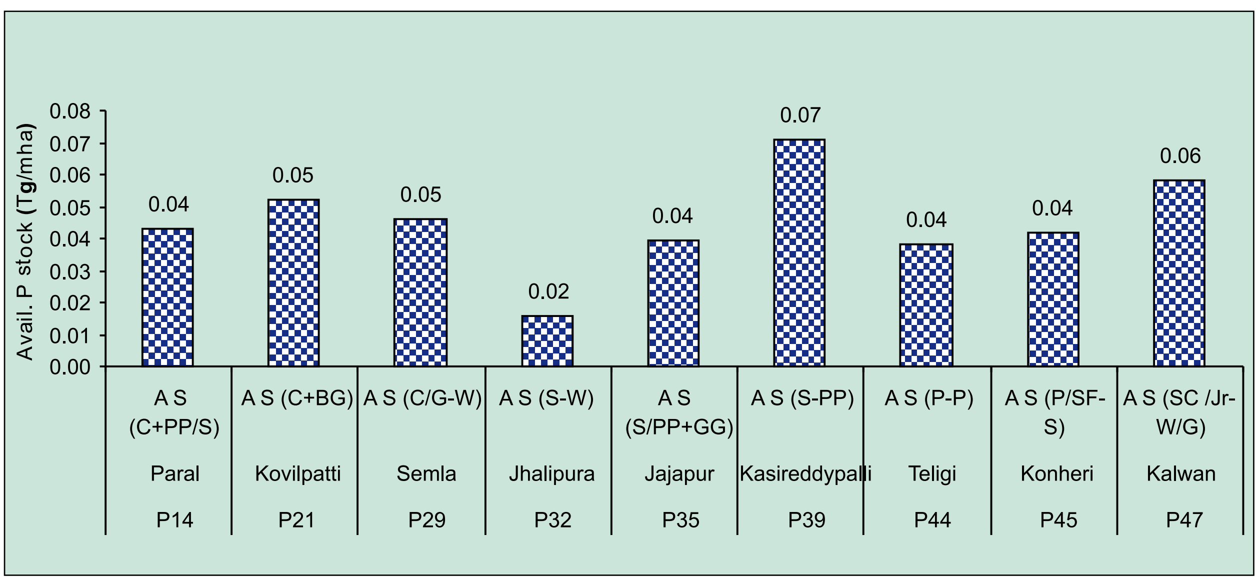


Figure 3.6.16. Available P stocks in black sols (0–30 cm depth) in arid (dry) bioclimatic zone.

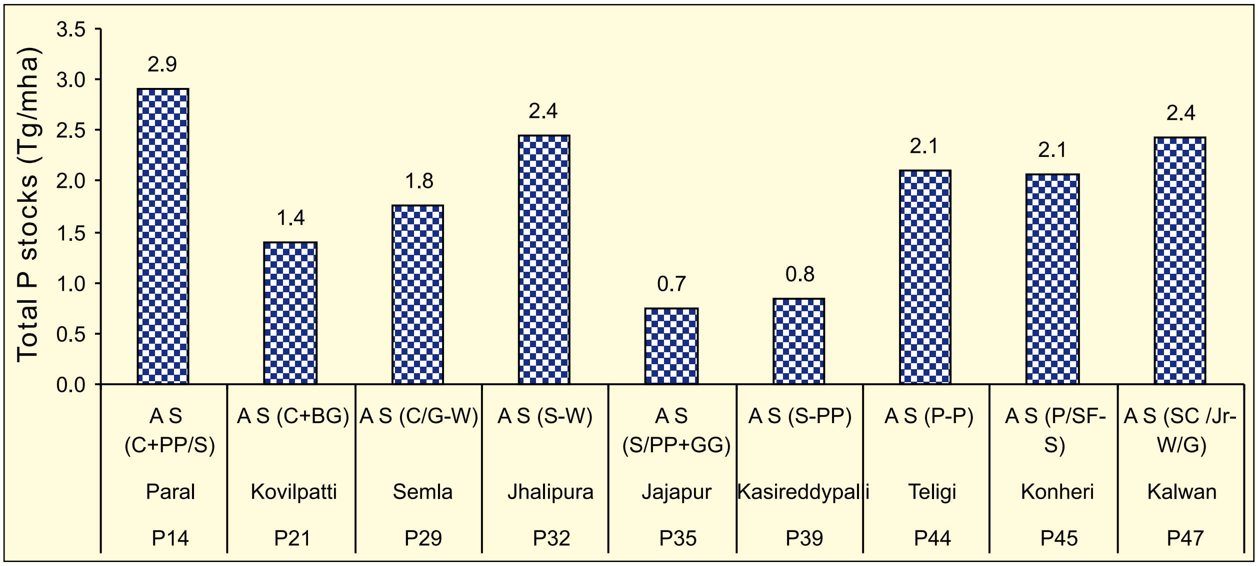


Figure 3.6.17. Available P stocks in semi-arid (dry) bioclimatic zone (0–30 cm) in black soils.

Table 3.6.6. Total P and available P stocks in black soils of semi-arid dry zone in SAT, India.

Pedon no.	Series	Systems (crop)	Total P stock (Tg/mha^{-1}) Soil depth (cm) 0–30	0–50	0–100	0–150	Avail. P stock (Tg/mha^{-1}) Soil depth (cm) 0–30	0–50	0–100	0–150
P32	Jhalipura	AS (FM) Soybean-Wheat	2.44	3.46	5.67	8.02	0.02	0.02	0.04	0.05
P33	Jhalipura	AS (FM II) Paddy-Wheat	2.18	3.28	5.13	6.92	0.02	0.02	0.04	0.05
P13	Paral	AS (LM) Cotton-Sorghum-Pigeonpea	2.72	4.43	8.50	12.61	0.04	0.06	0.10	0.15
P14	Paral	AS (HM) Cotton-Pigeonpea -Sorghum	2.90	4.74	10.62	11.83	0.04	0.07	0.13	0.18
P35	Jajapur	AS (FM I) Sorg-PP-G	0.75	1.09	1.79	2.51	0.04	0.07	0.13	0.18
P36	Jajapur	AS (FM II) Paddy-Paddy	2.14	2.96	4.14	4.94	0.08	0.12	0.21	0.28
P39	Kasireddi palli	AS (HM) S-PP Inter cropping	0.84	1.27	2.45	3.63	0.07	0.13	0.20	0.26
P40	Kasireddi palli	AS (TM) Fallow-Gram	0.92	1.38	2.48	3.53	0.04	0.07	0.13	0.18
P45	Konheri	AS (FM) Pigeonpea/ Sunflower Fallow-Sorghum	2.07	3.48	6.76	9.56	0.04	0.07	0.12	0.17
P46	Konheri	AS (LM) Fallow-Sorghum	1.35	2.24	4.36	6.17	0.03	0.06	0.10	0.14
P47	Kalwan	AS (FM) MA-SC/On/ Wheat	2.43	3.38	6.25	9.65	0.06	0.09	0.17	0.24
P19	Kovilpatti	AS (original) Sorghum	0.93	1.54	2.93	4.35	0.02	0.03	0.05	0.06
P20	Kovilpatti	Wasteland	0.94	1.42	2.75	4.22	0.03	0.04	0.07	0.08
P21	Kovilpatti	AS (HM) Cotton	1.40	2.09	3.45	6.30	0.05	0.08	0.12	0.14
P29	Semla	AS (FM) Groundnut/ Cotton	1.75	2.56	4.25	5.90	0.05	0.07	0.13	0.18
P43	Teligi	AS (LM) Paddy-Paddy	1.59	2.34	3.79	5.18	0.04	0.07	0.12	0.16
P44	Teligi	AS (HM) PP	2.10	2.88	4.27	5.66	0.04	0.06	0.11	0.15

Red Soils

Data given in Table 3.6.7 indicate that the total and available P stocks in red soils range from 0.62 to 5.32 Tg mha^{-1} and 0.040 to 0.065 Tg mha^{-1}, respectively. Exceptionally high total phosphorus stock (5.32 Tg mha^{-1}) was observed in Palathurai series under horticultural system (P22)(Figures 3.6.18 and 3.6.19), followed by soils with less that 1 Tg mha^{-1} stock in other series. The higher levels of total and available P stocks in soils of Palathurai series were not due to the parent material which contained high total P content. It might have been due to the presence of certain P-bearing clay minerals which needs further investigation.

Table 3.6.7. Total P and available P stocks in red soils of semi-arid dry zone in SAT, India.

Pedon no.	Series	Systems (crop)	Total P stock (Tg/mha^{-1}) Soil depth (cm) 0–30	0–50	0–100	0–150	Avail. P stock (Tg/mha^{-1}) Soil depth (cm) 0–30	0–50	0–100	0–150
P37	Hayatnagar	AS (HM) Sorghum-Castor	0.96	1.50	4.52	8.35	0.05	0.08	0.14	0.21
P38	Hayatnagar	AS (LM) Sorghum-Castor	1.30	2.04	7.19	14.53	0.05	0.08	0.13	0.20
P41	Patancheru	Fallow system Grass land	0.62	0.98	2.18	4.25	0.04	0.06	0.12	0.27
P34	Kaukuntla	AS (FM) Castor+ Pigeonpea	0.77	1.10	1.80	2.45	0.05	0.07	0.14	0.18
P22	Palathurai	Horticulture (original) Tomato	5.32	8.94	26.28	17.69	0.07	0.09	0.15	0.20

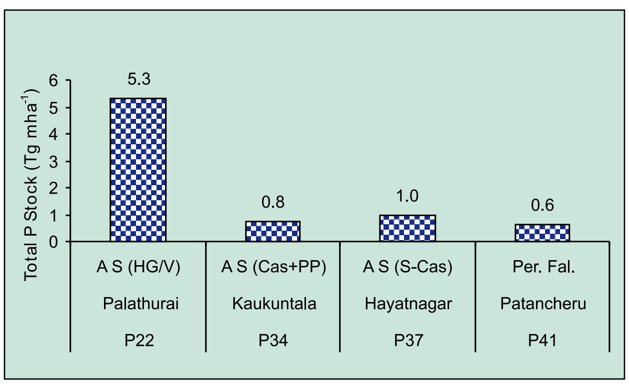


Figure 3.6.18. Total P stocks in semi-arid (dry) bioclimatic zone (0–30 cm) in red soils.

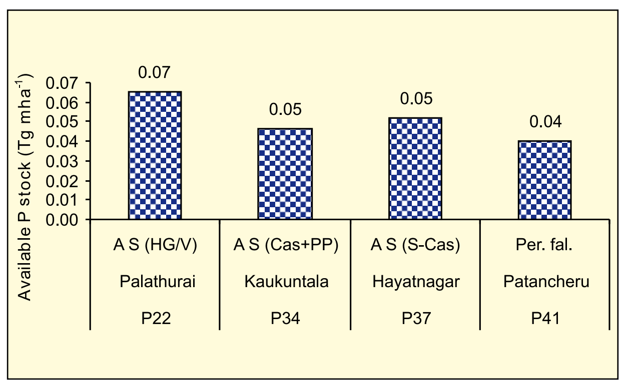


Figure 3.6.19. Available P stocks in semi-arid (dry) bioclimatic zone (0–30 cm) in red soils.

3.6.2.5 Arid

Black Soils

The data on total and available P stocks at various depths are given in Table 3.6.8. Total and available P content ranged from 0.60 to 2.48 Tg mha^{-1} and 0.01 to 0.05 Tg mha^{-1}, respectively, in black soils of arid zone. Nimone series (P51) under high-management system with cotton/wheat-chickpea rotation recorded highest total and available P contents. Under Nimone series, soils with high-management system had 49.3% and 31.2% higher levels of total P and available P stocks, respectively, than the farmers' management system. The levels of total and available P stocks in the soils of Nimone and Sokhda series are presented in Figures 3.6.20 and 3.6.21.

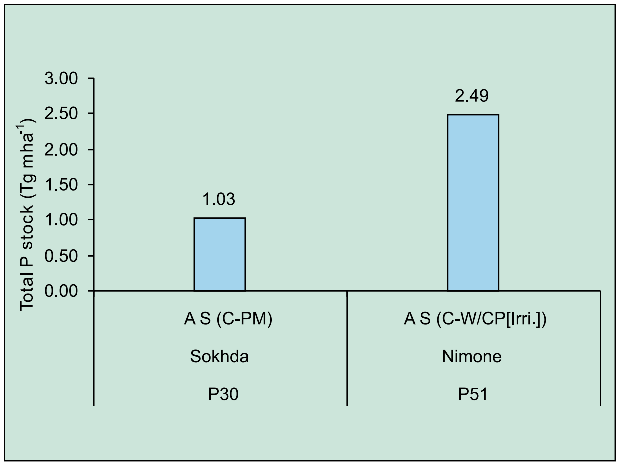


Figure 3.6.20. Total P stocks in arid bioclimatic zone (0–30 cm) in black soils.

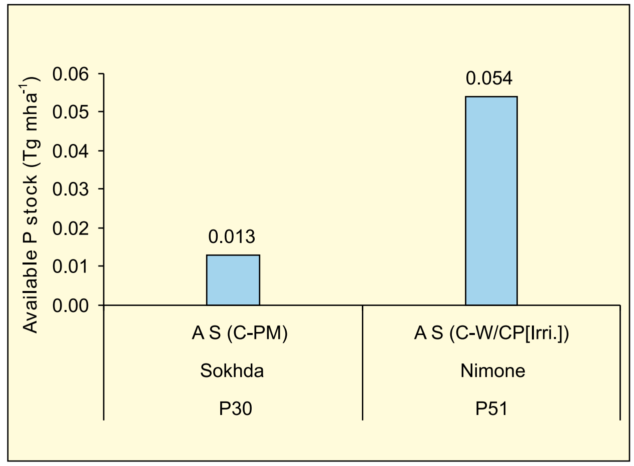


Figure 3.6.21. Available P stocks in arid bioclimatic zone in black soils (0–30 cm).

Table 3.6.8. Total P and available P stocks in black soils of arid zone in SAT, India.

			Total P stock (Tg/mha^{-1})				Avail. P stock (Tg/mha^{-1})			
			Soil depth (cm)				Soil depth (cm)			
Pedon no.	Series	Systems (crop)	0–30	0–50	0–100	0–150	0–30	0–50	0–100	0–150
P30	Sokhda	AS (FM I) Cotton/Pearl millet	1.03	1.78	3.80	5.05	0.01	0.02	0.04	0.05
P31	Sokhda	AS (FM II) Cotton-Pearl millet/Linseed	0.60	1.02	2.35	3.60	0.01	0.02	0.04	0.05
P51	Nimone	AS (HM) Cotton-Wheat/ Chickpea (Irrigated)	2.49	4.04	7.66	0.05	0.09	0.17	0.25	11.39
P52	Nimone	AS (FM) Sugarcane-Soybean/ Wheat/Chickpea	1.67	2.85	5.44	7.60	0.04	0.07	0.13	0.18

3.6.3 Variation in soil phosphorus stocks under different land-use systems

The total and available P stocks of black soils at 0–30 cm depth under different land-use are given in Figures 3.6.22 and 3.6.23, respectively. The P stocks in red soils are given in Figures 3.6.24 and 3.6.25. Horticultural system had highest P stocks in black soils. In red soils, P stocks were high under forest system. Horticultural system generally received good amount of nutrients as they are considered high-value crops.

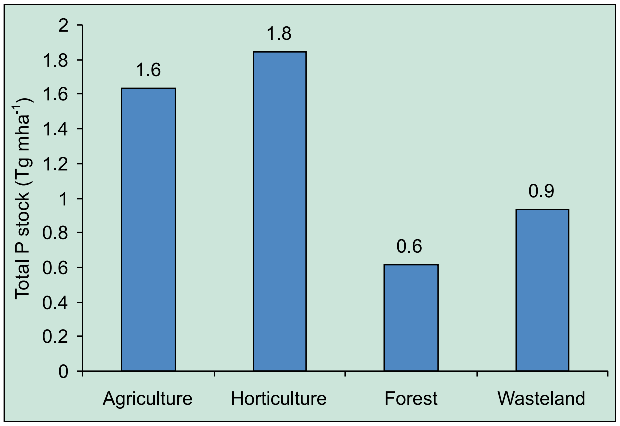


Figure 3.6.22. Total P stocks in black soils at (0–30 cm) depth in different land-use systems.

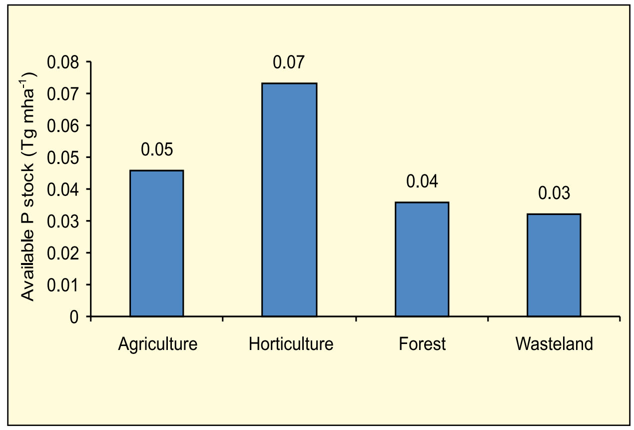


Figure 3.6.23. Available P stocks in black soils at (0–30 cm) depth in different land-use systems.

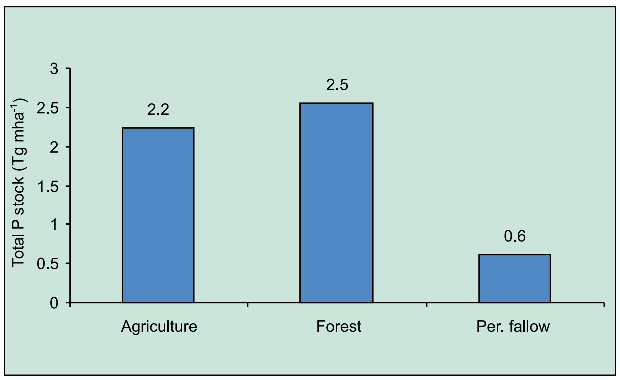
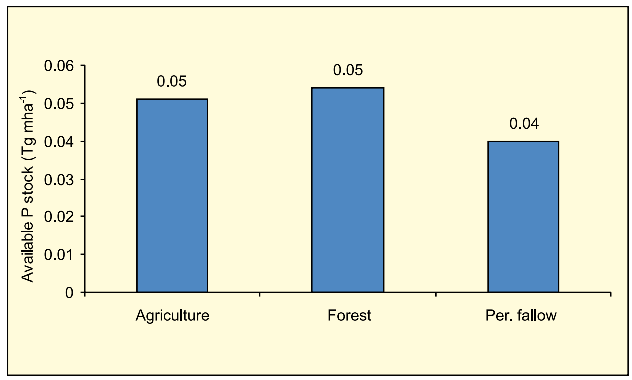


Figure 3.6.24. Total P stocks in red soils at (0–30 cm) depth in different land-use systems.



Figuer 3.6.25. Available P stocks in red soils at (0–30 cm) depth in different land-use systems.

3.7. Available Sulphur

Sulphur in dryland agriculture is now gaining importance because of the recognition of its role in increasing crop production, especially in different cropping systems which are marked by application of no or less sulphur. Less information exists regarding sulphur availability and its dynamics in tropical/sub-tropical soils in general and semi-arid tropics in particular, which may differ considerably from those in other climates (Neptune et al. 1975). Soil sulphur exists in organic form, adsorbed and in soil solution as SO_4^{-}. Available sulphur or sulphate sulphur is the primary source of sulphur taken up by most of the crops. Soil-solution sulphate level determines the amount of S available to plant. The source of the solution sulphate is the organic matter via the microbial pool or directly from animal residues, atmospheric inputs or fertilizers. A major source of solution sulphate is desorption of S held on the adsorption complex. If the crop demand for the main nutrients such as N, P and K are met, then S may become limiting, especially when fertilizers with no or low S substitute fertilizers containing large amounts of sulphur. Organic S is generally the most abundant form of sulphur in agricultural soils with rapid fluxes between plant available, inorganic and organic S fractions. As sulphur is also one of the key components of soil organic matter, understanding its dynamics under varied bioclimatic systems and land-use helps to understand its relationship with other major soil parameters. This in turn will help identify suitable systems for increased carbon sequestration in semi-arid tropical soils.

3.7.1 Variation of available S in different bioclimatic zones

3.7.1.1 Black soils

The content of available S in black soils at 0–30 cm depth under different bioclimatic zones is given in Figure 3.7.1. The content varied between 8 mg kg^{-1} soil in sub-humid (moist) to 14 mg kg^{-1} soil in semi-arid (dry) zone. With decrease in the rainfall, the amount of available S increased upto semi-arid (dry). The low content of AS in SH (M) zone could be attributed to the leaching of sulphur due to high rainfall. No significant positive relationship was observed with any of the soil parameters studied.

3.7.1.2 Red soils

Available S content of red soils in 0–30 cm depth is given in Figure 3.7.2. As in black soils, with decrease in rainfall the available S content increased upto semi-arid (moist) zone and decreased thereafter. The average available S content of red soil was less than that in black soil in all the bioclimatic zones.

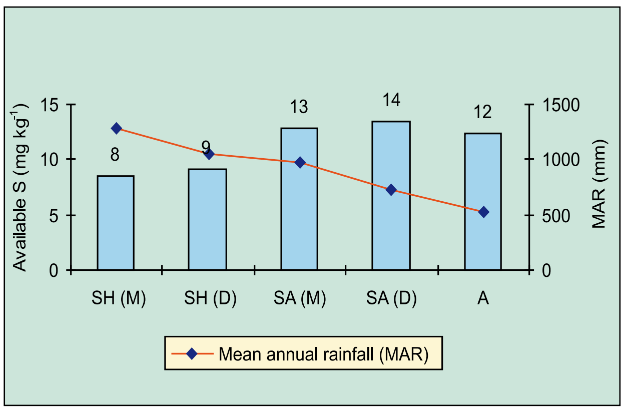


Figure 3.7.1. Available S content of black soils at 0–30 cm depth in different bioclimatic zones.

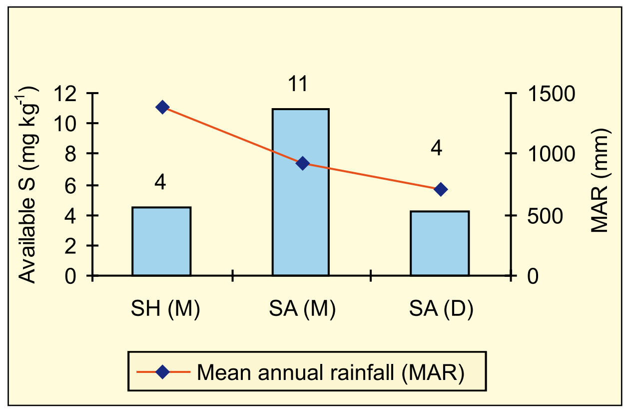


Figure 3.7.2. Available S content of red soils at 0–30 cm depth in different bioclimatic zones.

3.7.2 Variation of available S in different benchmark spots

Black Soils

3.7.2.1 Sub-humid (moist)

The content of available S at various depths in sub-humid (moist) zone is presented in Table 3.7.1.

Table 3.7.1. Profile distribution of available S in various benchmark locations of black soils under sub-humid (moist) zone.

				Avail. S (mg kg^{-1})			
				Soil depth (cm)			
Sl. no.	Series	System	P. no.	0–30	0–50	0–100	0–150
1.	Kheri	Agriculture (HM) Rice/Wheat/Maize	P27	11	9	8	8
2.	Kheri	Agriculture (FM) Soybean-Wheat	P28	4	4	4	5
3.	Boripani	Reserve forest teak	P15	5	6	7	7
4.	Nabibagh	Agriculture (HM)Soybean-Wheat	P5	11	10	9	11
5.	Nabibagh	Agriculture (FM) Soybean-Wheat, Gram	P6	9	8	8	7
6.	Panjri	Agriculture (HM) Cotton	P4	11	12	13	13

The content of available S varied between 4 mg kg^{-1} in Kheri series (P28) under farmer's management and 11 mg kg^{-1} in Nabibagh, Panjri and Kheri series under high-management systems. The content of available S was higher in 0–30 cm depth but did not vary considerably with depth.

3.7.2.2 Sub-humid (dry)

The content of available S at various depths in sub-humid (dry) zone is given in Table 3.7.2.

Table 3.7.2. Profile distribution of available S in black soils in various benchmark spots under sub-humid (dry) zone.

				Avail. S (mg kg^{-1})			
				Soil depth (cm)			
Sl. no.	Series	System	P. no.	0–30	0–50	0–100	0–150
1.	Nipani	Agriculture (FM) Cotton+Pigeonpea and alternative Sorghum and Maize	P48	6	6	6	6
2.	Pangidi	Agriculture (FM) Soybean+Pigeonpea	P49	5	5	5	5
3.	Pangidi	Agriculture Soybean	P50	5	6	6	5
4.	Sarol	Agriculture (HM) Soybean-Wheat	P7	11	13	13	15
5.	Sarol	Agriculture (FM) Soybean-Wheat	P8	12	12	13	14
6.	Sarol	Agriculture (HM) Soybean-Gram	P9	9	11	14	14
7.	Linga	Horticulture (HM) Orange	P1	11	13	19	23
8.	Linga	Horticulture (LM) Orange	P3	16	17	17	16
9.	Linga	Agriculture (FM) Soybean-Gram/Wheat	P2	6	7	8	8

The content of available S varied between 5 mg kg^{-1} in Pangidi series (P49 and P50) and 16 mg kg^{-1} in Linga series (P3). In P1 and P7 of Sarol series, the content of available S increased with increasing depth, whereas in most of the other series it is more or less the same. In general, horticultural system contained a higher amount of available S in 0–30 cm depth than agricultural soils.

3.7.2.3 Semi-arid (moist)

The content of available S at various depths in semi-arid (moist) zone is presented in Table 3.7.3.

Table 3.7.3. Profile distribution of available S in various benchmark locations of black soils under semi-arid (moist) zone.

				Avail. S (mg kg^{-1})			
				Soil depth (cm)			
Sl. no.	Series	System	P. no.	0–30	0–50	0–100	0–150
1.	Bhatumbra	Agriculture (FM) Sorghum+ Pigeonpea/Black gram-Chickpea	P42	18	15	15	11
2.	Asra	Agriculture (FM) CO-GG-PP IC CO/ PP	P10	11	11	11	12
3.	Asra	Agriculture (FM) Soybean-Pigeonpea intercropping Soy/PP	P11	8	9	9	10
4.	Asra	Agriculture (HM) Soybean-Gram-Cotton-Pigeonpea	P12	15	14	12	13

The content of available S in the soils of semi-arid (moist) zone varied between 8 mg kg^{-1} in Asra series (P11) and 18 mg kg^{-1} in Bhatumbra series (P42). There was no significant variation in the content of available S with depth. The high content of available S in soils of Bhatumbra series could be attributed to the nature of cropping system and those of P12 due to the high-management system.

3.7.2.4 Semi-arid (dry)

The content of available S at various depths in semi-arid (dry) zone are presented in Table 3.7.4.

Table 3.7.4. Profile distribution of available S in black soils in various benchmark spots under semi-arid (dry) zone.

				Avail. S (mg kg^{-1})			
Sl. no.	Series	System	P. no.	0–30	0–50	0–100	0–150
1.	Jhalipura	Agriculture (FM) Soybean-Wheat	P32	21	19	18	18
2.	Jhalipura	Agriculture (FM II) Paddy-Wheat	P33	97	71	49	39
3.	Paral	Agriculture (LM) Cotton-Sorghum-Pigeonpea	P13	7	7	7	12
4.	Paral	Agriculture (HM) Cotton-Pigeonpea-Sorghum	P14	8	8	7	12
5.	Jajapur	Agriculture (FM I) Sorghum-Pigeonpea-Green gram	P35	4	5	7	11
6.	Jajapur	Agriculture (FM II) Paddy-Paddy	P36	5	5	5	10
7.	Kasireddi-palli	Agriculture (HM) Soybean-Pigeonpea Inter cropping	P39	14	14	15	17
8.	Kasireddi-palli	Agriculture (TM) Fallow-Gram	P40	6	6	7	49
9.	Konheri	Agriculture (FM) Pigeonpea/Sunflower Fallow-Sorghum	P45	4	4	5	5
10.	Konheri	Agriculture (LM) Fallow-Sorghum	P46	6	6	7	6
11.	Kalwan	Agriculture (FM) Maize-Sugarcane/Onion/Wheat	P47	7	7	8	8
12.	Kovilpatti	Agriculture (original) Sorghum	P19	10	13	14	134
13.	Kovilpatti	Wasteland	P20	6	7	9	14
14.	Kovilpatti	Agriculture (HM) Cotton	P21	19	24	29	141
15.	Semla	Agriculture (FM) Groundnut/Cotton	P29	5	4	17	21
16.	Teligi	Agriculture (LM) Paddy-Paddy	P43	5	5	5	8
17.	Teligi	Agriculture (HM) Paddy-Paddy	P44	4	4	7	18

The content of available S varied between as low as 4 mg kg^{-1} in Jajapur series (P35), Konheri series (P45) and Teligi series (P44) and as high as 97 mg kg^{-1} in Jhalipura series (P33). The reason for the high available S in P33 was due to the paddy-wheat system under farmers' management, where the application of sulphur-containing complex fertilizers and organic matter was practised. The low content of available S could be attributed to the low inherent content of available S in these soils coupled with low or no application of sulphur-containing fertilizers under dryland cropping systems. However in P44, the content of available S was very low despite paddy-paddy system. Significant increase in the content of available S with increase in depth was noticed in Kovilpatti series (P21), which was due to the presence of gypsum crystals at lower depths. However, due to topographic differences at the sites, this trend was not seen in the soils of other Kovilpatti series (P19 and P20).

3.7.2.5 Arid

Available S in various depths in arid zone soils is presented in Table 3.7.5.

Table 3.7.5. Profile distribution of available S in various benchmark spots of black soils under arid zone.

				Avail. S (mg kg^{-1})			
				Soil depth (cm)			
Sl. no.	Series	System	P. no.	0–30	0–50	0–100	0–150
1.	Sokhda	Agriculture (FM I) Cotton/Pearl millet	P30	5	5	6	6
2.	Sokhda	Agriculture (FM II) Cotton-Pearl millet/ Linseed	P31	5	5	7	18
3.	Nimone	Agriculture (HM) Cotton-Wheat/ Chickpea (Irrigated)	P51	24	33	185	590
4.	Nimone	Agriculture (FM) Sugarcane-Soybean/ Wheat/Chickpea	P52	16	19	25	26

The content of available S at 0–30 cm varied between 5 mg kg^{-1} in Sokhda series (P30 and P31) and 24 mg kg^{-1} in Nimone series (P51). Moreover, in soils of Nimone series, the content of available S increased with depth in contrast to other soil series. It was maximum at 590 mg kg^{-1} at 0–150 depth in P51, which could be primarily attributed to parent material containing sulfates. This soil was present in foothills and was considerably different from P52.

Red Soils

3.7.2.6 Sub-humid (moist)

The content of available S at various depths in sub-humid (moist) zone is presented in Table 3.7.6.

Table 3.7.6. Profile distribution of available S in various benchmark spots of red soils under sub-humid (moist) zone.

				Avail. S (mg kg^{-1})			
Sl. no.	Series	System	P. no.	0–30	0–50	0–100	0–150
1.	Dadarghugri	Agriculture (LM) Maize-Mustard (Pigeonpea)	P23	6	4	1	1
2.	Dadarghugri	Forest system teak	P24	1	1	1	1
3.	Karkeli	Forest system sal	P25	3	2	2	2
4.	Karkeli	Agriculture (LM) Sweet potato/MM (kodo)	P26	8	8	7	5

The content of available S varied between 1 mg kg^{-1} in Dadarghugri series (P24) and 8 mg kg^{-1} in Karkeli series (P26). The soil of forest systems was found to have lower content of available S compared to agricultural systems.

3.7.2.7 Semi-arid (moist)

Available S at various depths in semi-arid (moist) zone is given in Table 3.7.7.

Table 3.7.7. Profile distribution of available S in red soils in various benchmark spots under semi-arid (moist) zone.

				Avail. S (mg kg^{-1})			
Sl. no.	Series	System	P. no.	0–30	0–50	0–100	0–150
1.	Vijayapura	Agriculture (FM) Finger millet	P16	4	4	4	12
2.	Vijayapura	Agriculture (original) Pulses	P17	9	13	15	12
3.	Vijayapura	Agriculture (HM) Finger millet	P18	20	17	21	17

The content of available S varied between 4 mg kg^{-1} to 20 mg kg^{-1} in the sole series of Vijayapura. However, the highest content of available S was observed under high-management system (P18), a single crop was cultivated with application of high quantity of fertilizer containing sulphur.

3.7.2.8 Semi-arid (dry)

The content of available S at various depths in semi-arid (dry) zone is presented in Table 3.7.8.

Table 3.7.8 Profile distribution of available S in red soils in various benchmark spots under semi-arid (dry) zone.

				Avail. S (mg kg^{-1})			
Sl. no.	Series	System	P. no.	0–30	0–50	0–100	0–150
1.	Hayatnagar	Agriculture (HM) Sorghum-Castor	P37	4	4	5	5
2.	Hayatnagar	Agriculture (LM) Sorghum-Castor	P38	7	7	6	5
3.	Patancheru	Fallow system Permanent fallow Grassland	P41	2	2	4	5
4.	Kaukuntla	Agriculture (FM) Castor+Pigeonpea	P34	5	5	4	3
5.	Palathurai	Horticulture (original) Tomato	P22	3	4	4	4

The content of available S in this zone was low and varied between 2 mg kg^{-1} in the soils of Patancheru series (P41) and 7 mg kg^{-1} in the soils of Hayatnagar series (P38). Despite the high organic carbon content of Patancheru series under fallow grassland system, lowest available S (2 mg kg^{-1}) was observed here. In low-management system of Hayatnagar series, high content of available S was observed.

3.7.3 Variation of available S under different land-use systems

Figures 3.7.3 and 3.7.4 illustrate the distribution of available S content in black and red soils in different land-use systems. It was observed that soils under horticultural system were found to have maximum content of available S, closely followed by agricultural system. Wasteland and forest soils had the lowest content of available S. Probably the high organic carbon content under agricultural and horticultural systems might be responsible for the high available S content. In red soils, agricultural system was found to have maximum available S whereas the permanent fallow and forest system were found to have the lowest available S. The trend with respect to different land-uses on the content of available sulphur, irrespective of soil types, indicates the importance of addition of inputs that improve carbon and sulphur content, which greatly enhance the content of soils.

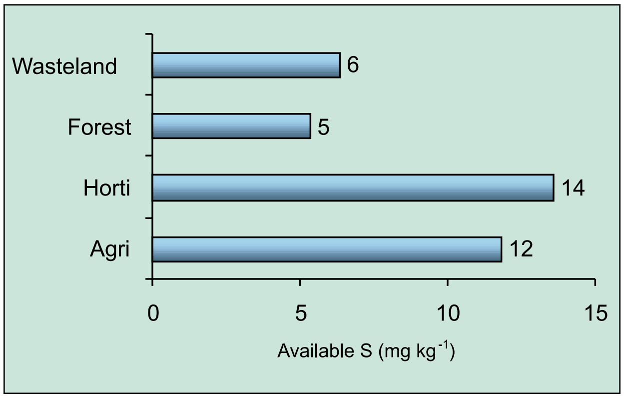


Figure 3.7.3. Variation in available S content of black soils at 0–30 cm depth under different land-use systems.

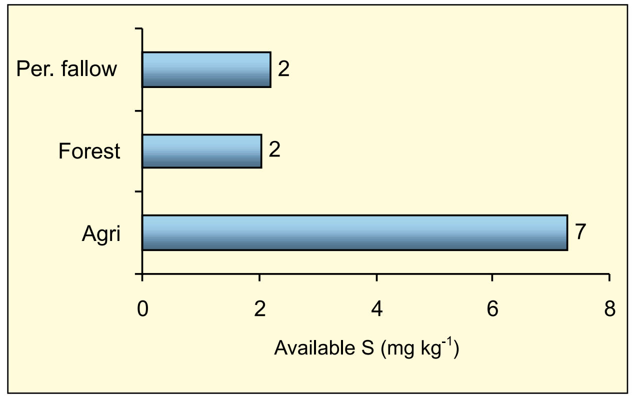


Figure 3.7.4. Variation in available S content of red soils at 0–30 cm depth under different land-use systems.

3.8 Sulphur Stocks

3.8.1 Variation of available S stocks in different bioclimatic zones

3.8.1.1 Black soils

Available sulphur stocks at 0–30 cm depth in various bioclimatic zones is given in Figure 3.8.1.

3.8.1.2 Red soils

Available sulphur stocks at 0–30 cm depth in red soils in different bioclimatic zones is given in Figure 3.8.2

Results revealed that under optimum rainfall conditions in the semi-arid climate, the availability of sulphur was found to be maximum in both soil types.

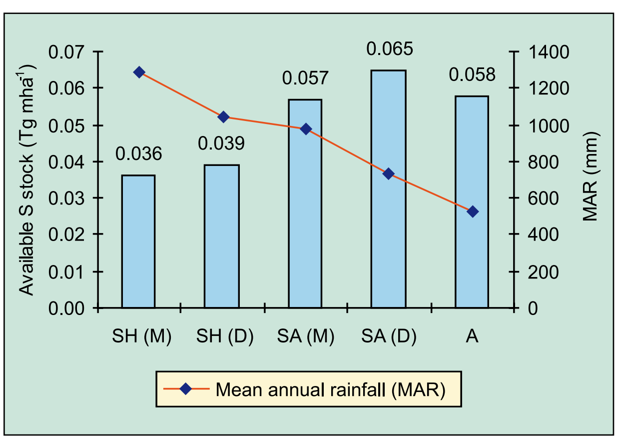


Figure 3.8.1. Available sulphur stocks of black soils at 0–30 cm depth in different bioclimatic zones.

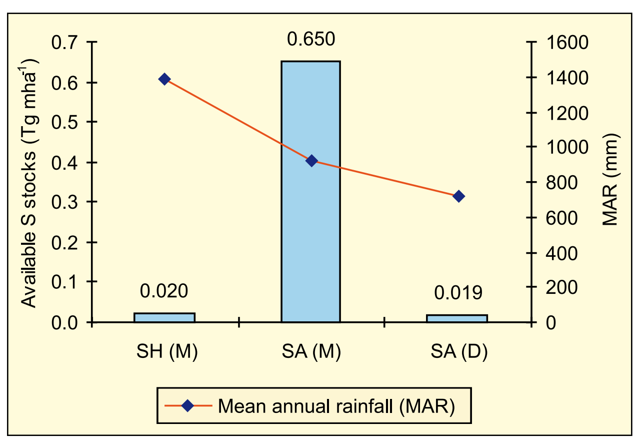


Figure 3.8.2. Available sulphur stocks of red soils at 0–30 cm depth in different bioclimatic zones.

3.8.2 Variation of available S stocks in different benchmark spots

3.8.2.1 Sub-humid (moist)

Black Soils

The data on available S stocks of black soils in sub-humid moist zone are given in Table 3.8.1. The available S stock ranged from 0.02 to 0.05 Tg mha^{-1}. Higher stock of available S was observed in Panjri series (P4) whereas it was low in Boripani series (P15) (Figure 3.8.4). Results also indicated that higher management systems resulted in higher levels of available S stocks.

Table 3.8.1. Available S stocks in black soils of sub-humid (moist) zone in SAT, India.

			Avail. S Stock (Tg mha^{-1})			
			Soil depth (cm)			
Pedon no.	Series	System	0–30	0–50	0–100	0–150
P27	Kheri	AS (HM) Rice/Wheat/Maize	0.05	0.07	0.12	0.19
P28	Kheri	AS (FM) Soybean-Wheat	0.02	0.03	0.06	0.10
P15	Boripani	Reserve forest teak	0.02	0.04	0.09	0.13
P5	Nabibagh	AS (HM) Soybean-Wheat	0.04	0.06	0.12	0.21
P6	Nabibagh	AS (FM) Soybean-Wheat, Gram	0.03	0.05	0.11	0.15
P4	Panjri	AS (HM) Cotton	0.05	0.09	0.19	0.29

Red Soils

Data on the available S content of red soils at various depths of sub-humid (moist) bioclimatic zone are given in Table 3.8.2. The stocks varied between 0.004 and 0.04 Tg mha^{-1}. Higher available S stocks in these red soils occurred in agricultural system under low management, which is under millet–sweet potato rotation, followed by high S levels in sal forests (Figure 3.8.5).

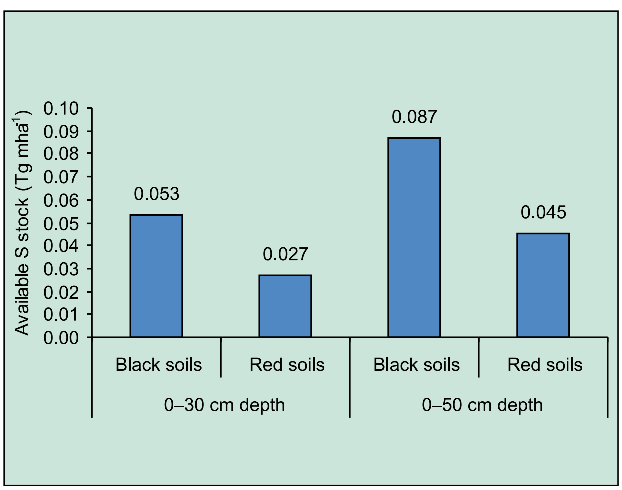


Figure 3.8.3. Available S stocks of black and red soils at various depths.

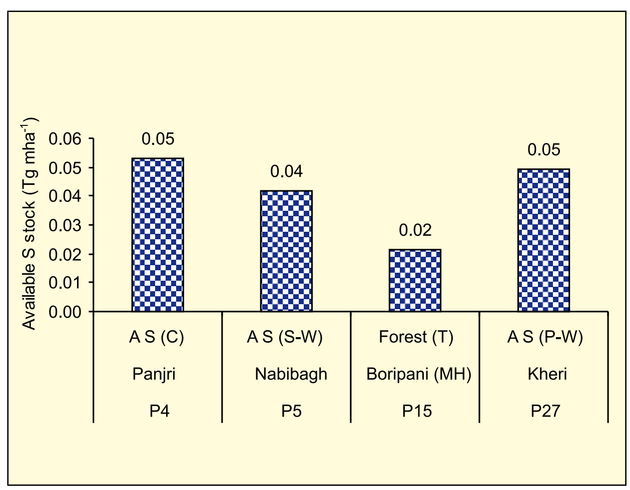


Figure 3.8.4. Available S stock in sub-humid (moist) bioclimatic system (0–30 cm) in black soils.

Table 3.8.2. Available S stocks in red soils of sub-humid (moist) zone in SAT, India.

			Avail. S stock (Tg mha^{-1})			
			Soil depth (cm)			
Pedon no.	Series	System (crop)	0–30	0–50	0–100	0–150
P23	Dadarghugri	AS (LM) Maize-Mustard (Pigeonpea)	0.02	0.02	0.01	0.02
P24	Dadarghugri	Forest system teak	0.004	0.005	0.01	0.02
P25	Karkeli	Forest system sal	0.01	0.02	0.04	0.04
P26	Karkeli	AS (LM) Sweet potato/minor millet (kodo)	0.04	0.06	0.11	0.12

3.8.2.2 Sub-humid (dry)

Black Soils

The data of available S stock in black soils of sub-humid (dry) zone are given in Table 3.8.3 and Figure 3.8.6. Results showed higher stock of available S in horticultural and agricultural systems, which ranged between 0.02 to 0.07 Tg mha^{-1}. The highest S level was in P3 and lowest in Pangidi series with farmers' management (P49). Low management under horticultural system (P3) recorded 2.8 times higher levels of available S stocks than soils of Pangidi series under agricultural system under farmers management (P49).

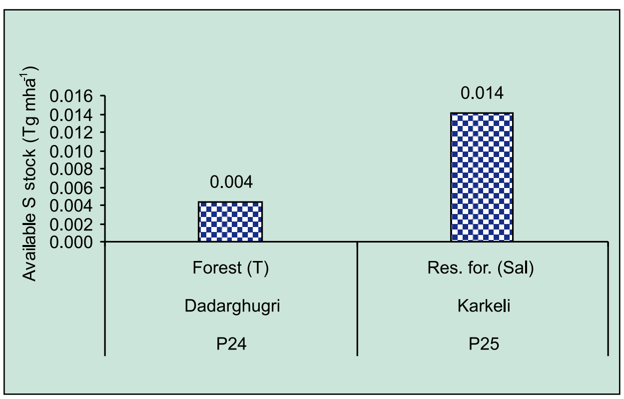


Figure 3.8.5. Available S stocks in sub-humid (moist) bioclimatic system (0–30 cm) in red soils.

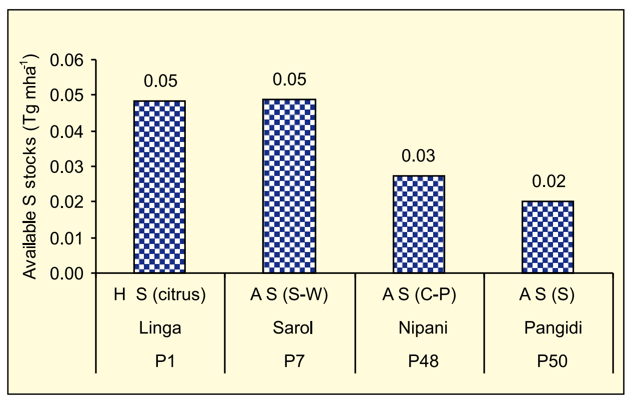


Figure 3.8.6. Available S stocks in sub-humid (dry) bioclimatic system (0–30 cm) in black soils.

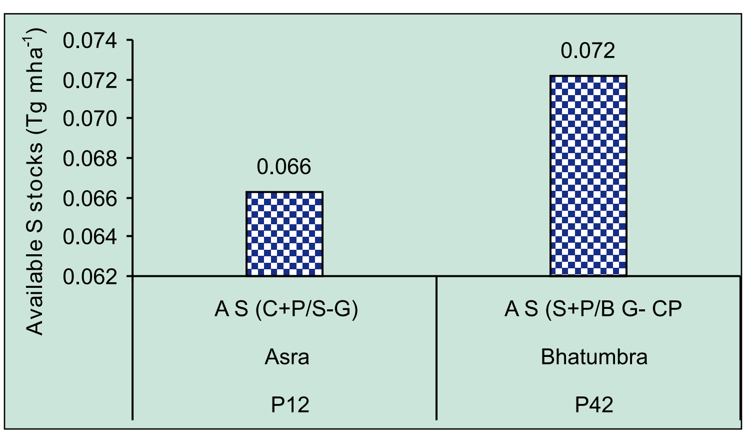


Figure 3.8.7. Available S stocks in semi-arid (moist) bioclimatic system (0–30 cm) in black soils.

Table 3.8.3. Available S stocks in black soils of sub-humid (dry) zone in SAT, India.

			Avail. S stock (Tg mha^{-1})			
			Soil depth (cm)			
Pedon no.	Series	System (crop)	0–30	0–50	0–100	0–150
P48	Nipani	AS (FM) Cotton+Pigeonpea & alternative Sorghum and Maize	0.03	0.04	0.09	0.14
P49	Pangidi	AS (FM) Soybean+Pigeonpea	0.02	0.03	0.06	0.09
P50	Pangidi	AS Soybean	0.02	0.04	0.07	0.11
P7	Sarol	AS (HM) Soybean-Wheat	0.05	0.09	0.19	0.33
P8	Sarol	AS (FM) Soybean-Wheat	0.05	0.08	0.19	0.28
P9	Sarol	AS (HM)Soybean-Gram	0.04	0.08	0.19	0.30
P1	Linga	Horticulture (HM) Orange	0.05	0.09	0.26	0.47
P3	Linga	Horticulture (LM) Orange	0.07	0.12	0.24	0.34
P2	Linga	AS (FM) Soybean-Gram/Wheat	0.03	0.05	0.12	0.19

3.8.3 Semi-arid (moist)

Black Soils

Data on the available S stocks in black soils at various depths in semi-arid (moist) zone are given in Table 3.8.4. Available S stock ranged from 0.04 to 0.07 Tg mha^{-1} with minimum and maximum stocks in soils of Asra series in P11 and P12, respectively. Bhatumbra series (P42) under farmers' management recorded 9% higher stocks of available S than Asra series (P12), which was under high-management (Figure 3.8.7).

Table 3.8.4. Available S stocks in black soils of the semi-arid (moist) zone in SAT, India.

			Avail. S stock (Tg mha^{-1})			
			Soil depth (cm)			
Pedon no.	Series	System (crop)	0–30	0–50	0–100	0–150
P42	Bhatumbra	AS (FM) Sorghum+Pigeonpea/Black gram-Chickpea	0.07	0.10	0.19	0.21
P10	Asra	AS (FM) CO-Green gram-Pigeonpea intercropping Cotton/PP	0.05	0.09	0.18	0.28
P11	Asra	AS (FM) Soybean-Pigeonpea intercropping Soybean/PP	0.04	0.07	0.14	0.24
P12	Asra	AS (HM) Soybean-Gram-Cotton-Pigeonpea	0.07	0.10	0.18	0.30

Red Soils

The available S stocks at various depths are given in Table 3.8.5. The available S stock at 0–30 cm depth ranged from 0.02 to 0.09 Tg mha^{-1} among the soil series. Soils under high-management contained high levels of available S and the lowest stock was found with farmer's management levels (P16). These trends are dissimilar to those found in red soils of sub-humid (moist) zone where high S stock was observed under low management conditions.

Table 3.8.5 Available S stocks in red soils of semi-arid (moist) zone in, India.

			Avail. S Stock (Tg mha^{-1})			
			Soil depth (cm)			
Pedon no.	Series	System (crop)	0–30	0–50	0–100	0–150
P16	Vijayapura	AS (FM) Ragi	0.02	0.03	0.07	0.29
P17	Vijayapura	AS (original) Pulses	0.04	0.09	0.20	0.25
P18	Vijayapura	AS (HM) Ragi	0.09	0.12	0.30	0.36

3.8.4 Semi-arid dry

Black Soils

Data on available S stocks are given in Table 3.8.6. The stock ranged from 0.02 Tg mha^{-1} in soils of Konheri, Semla, Teligi and Jajapur series to 0.50 Tg mha^{-1} in soils of Jhalipura series (P33). Figure 3.8.8 shows the variation in S stocks in different series under various management systems. Jhalipura series under agricultural system with farmer's management recorded highest values of stock at 0–30 cm depth. Agricultural systems, paddy-wheat and soybean-wheat rotation system in farmer's management recorded higher values of available S than under high-management levels.

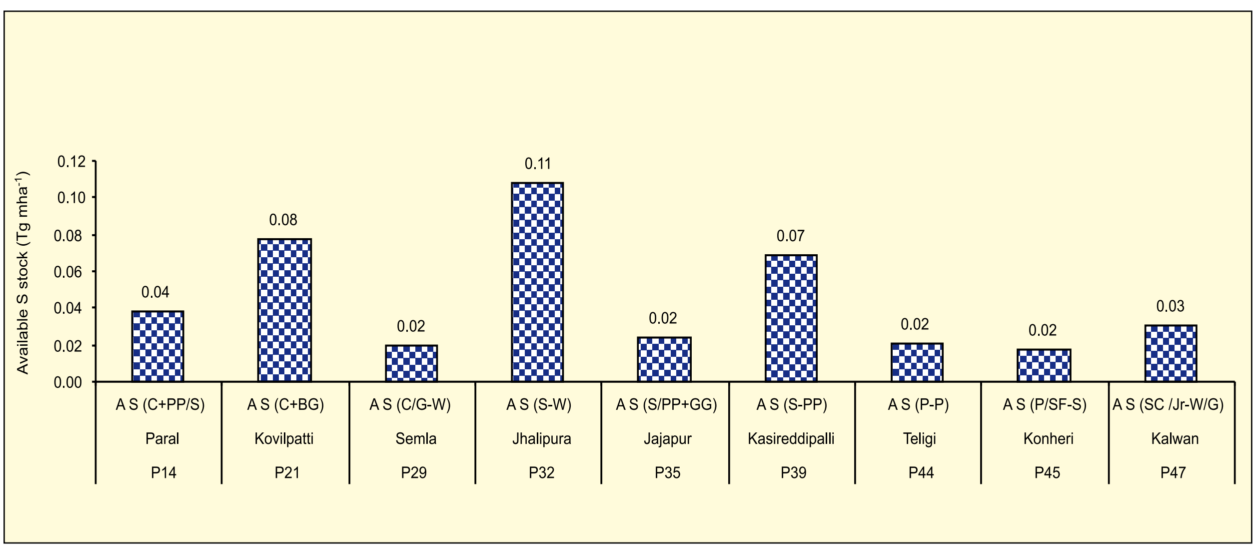


Figure 3.8.8 Available S stocks in semi-arid (dry) bioclimatic system (0–30 cm) in black soils.

Table 3.8.6. Available S stocks in black soils of semi-arid (dry) zone in, India.

Pedon no.	Series	System (crop)	Avail. S Stock (Tg mha^{-1}) Soil depth (cm) 0–30	0–50	0–100	0–150
P32	Jhalipura	AS (FM) Soybean-Wheat	0.11	0.15	0.30	0.45
P33	Jhalipura	AS (FM II) Paddy-Wheat	0.50	0.59	0.83	0.99
P13	Paral	AS (LM)Cotton-Sorghum-Pigeonpea	0.03	0.05	0.11	0.28
P14	Paral	AS (HM)Cotton-Pigeonpea-Sorghum	0.04	0.06	0.12	0.29
P35	Jajapur	AS (FM I) Sorghum-Pigeonpea-Green gram	0.02	0.05	0.13	0.27
P36	Jajapur	AS (FM II) Paddy-Paddy	0.03	0.04	0.10	0.28
P39	Kasireddipalli	AS (HM) Soybean-pigeonpea intercropping	0.07	0.11	0.23	0.39
P40	Kasireddipalli	AS (TM)Fallow-Gram	0.03	0.05	0.12	0.17
P45	Konheri	AS (FM) Pigeonpea/Sunflower Fallow-Sorghum	0.02	0.03	0.07	0.12
P46	Konheri	AS (LM)Fallow-Sorghum	0.02	0.04	0.09	0.14
P47	Kalwan	AS (FM) Maize-Sugarcane/Onion/Wheat	0.03	0.05	0.11	1.17
P19	Kovilpatti	AS (original) Sorghum	0.04	0.09	0.20	2.82
P20	Kovilpatti	Wasteland	0.03	0.05	0.12	0.28
P21	Kovilpatti	AS (HM) Cotton	0.08	0.16	0.40	2.94
P29	Semla	AS (FM) Groundnut/Cotton	0.02	0.03	0.25	0.47
P43	Teligi	AS (LM) Paddy-Paddy	0.02	0.04	0.07	0.18
P44	Teligi	AS (HM) Paddy-Paddy	0.02	0.03	0.10	0.38

Red Soils

Data pertaining to available S stocks of semi-arid (dry) zone at various depths are given in Table 3.8.7 and Figure 3.8.9. The stocks ranged from 0.02 to 0.03 Tg mha^{-1}.

Table 3.8.7. Available S stocks in red soils of semi-arid (dry) zone in, India.

Pedon no.	Series	System (crop)	Avail. S stock (Tg mha^{-1}) Soil depth (cm) 0–30	0–50	0–100	0–150
P37	Hayatnagar	AS (HM) Sorghum-Castor	0.02	0.03	0.06	0.10
P38	Hayatnagar	AS (LM) Sorghum-Castor	0.03	0.06	0.09	0.11
P41	Patancheru	Fallow system Permanent fallow Grassland	0.01	0.02	0.07	0.12
P34	Kaukuntla	AS (FM) Castor+Pigeonpea	0.02	0.04	0.06	0.08
P22	Palathurai	Horticulture (original) Tomato	0.02	0.03	0.06	0.09

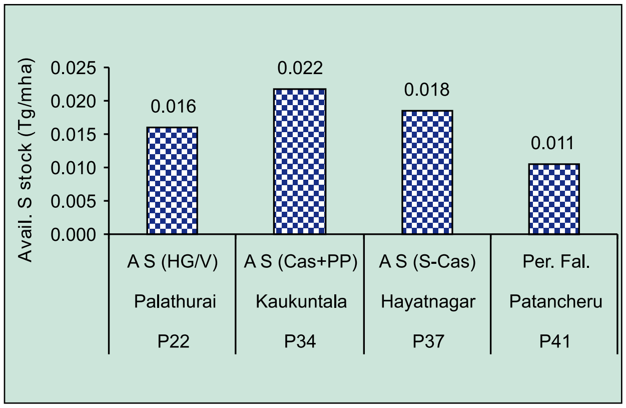


Figure 3.8.9 Available S stocks in semi-arid (dry) bioclimatic system in red soils (0–30 cm).

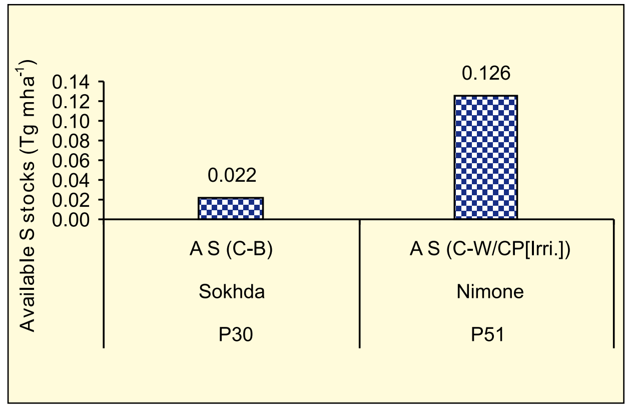


Figure 3.8.10 Available S stocks in arid bioclimatic system (0–30 cm) in black soils.

Higher available S stocks were observed in series P38 with sorghum-castor rotation under low-management system which is 66.6% and 36.34% higher than high-management and farmers' management systems, respectively.

3.8.2.5 Arid

Black Soils

Available S levels at various depths are given in Table 3.8.8 and Figure 3.8.10. The stock ranged from 0.02 Tg mha^{-1} in the soils of Sokhda series (P31) to 0.13 Tg mha^{-1} (P51) in the soils of Nimone series. Highest S stocks were in Nimone series (P51) under high-management. Among the Nimone series, available S stock was 94.4% more in soils under high-management than under farmers' management.

Table 3.8.8. Available S stocks in black soils of arid (dry) zone in, India.

			Avail. S stock (Tg mha^{-1})			
			Soil depth (cm)			
Pedon no.	Series	System (crop)	0–30	0–50	0–100	0–150
P30	Sokhda	AS (FM I) Cotton/Pearl millet	0.02	0.04	0.09	0.16
P31	Sokhda	AS (FM II) Cotton-Pearl millet/Linseed	0.02	0.04	0.11	0.43
P51	Nimone	AS (HM) Cotton-Wheat /Chickpea (Irrigated)	0.13	0.29	3.26	16.07
P52	Nimone	AS (FM) Sugarcane-Soybean/Wheat/Chickpea	0.06	0.13	0.35	0.54

3.8.3 Variation in soil sulphur stocks under different land-use systems

The variation in available S stock of black and red soils at 0–30 cm depth under different kinds of land use are given in Figures 3.8.11 and 3.8.12, respectively. The stocks followed a similar trend as that of available S content of soils and they were maximum under horticultural system in black soils and under agricultural system in red soils.

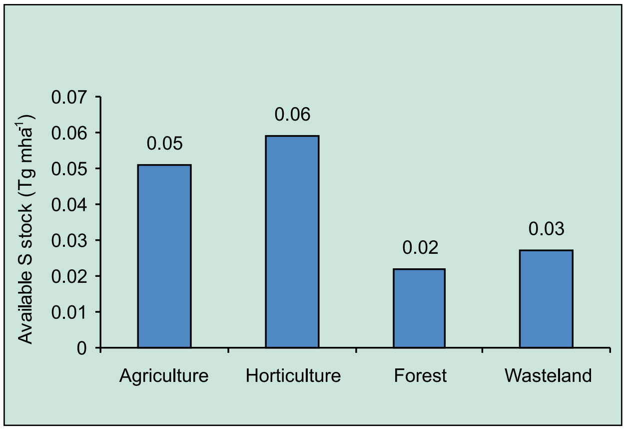


Figure 3.8.11. Available S stocks in black soils at 0–30 cm depth in different systems.

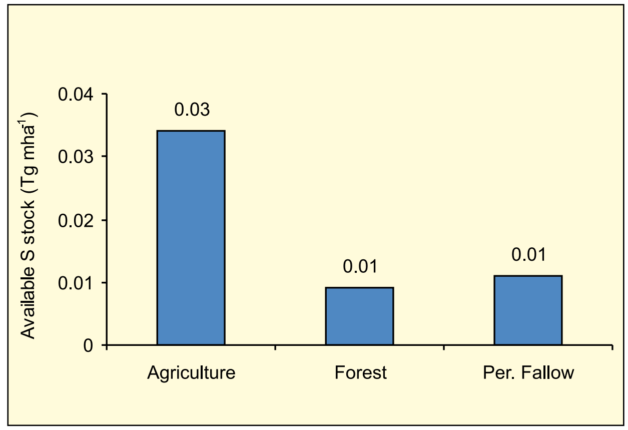


Figure 3.8.12. Available S stocks in red soils at 0–30 cm depth in different systems.

General Discussion

The present study on carbon sequestration was featured by various cropping systems under different land-uses representing various kinds of management levels and bioclimatic systems. Though considerable variation in total N and P concentration and stocks are prevalent in the soils of SAT India, which could be attributed to the nature of the parent material, other factors such as nutrient management erosion, loss of organic matter, and continuous cropping also played a key role in influencing the nutrient dynamics and carbon sequestration in soils. Moreover, soils and their management options are location and site specific. Dryland soils, which are characterized by low nutrient status and severe erosion (degradation) need to be more carefully dealt with from the viewpoint of sequestration of more carbon. Considering the average content of 0.036 to 0.0847% (by weight or grams of nitrogen in 100 g of soil) for total N in SAT soils and the average content of 0.014 to 0.186% for total P, which are low in average for SAT soils and considering the positive relationships of total N and P with organic carbon management practices such as application of recommended dose of fertilizers and incorporation of crop residues conservation tillage practices and such other best management practices (BMP's) can inevitably improve soil fertility. In the present study, too, irrespective of bioclimatic zones, land-use under horticultural (P1, P3) and agricultural systems (pedons P27, P49, P32, P36, P47, P43, P52) in general, and paddy systems in particular, had maximum content of total N. On these lines, textural improvement by way of practices like application of tank silt, practices for harboring more organic carbon should be promoted in red soils.

Nutrient elements in soils show dynamic behavior under influence of chemical, physical and biological processes. The intensity of processes depends on environmental conditions (temperature, rainfall) as well as soil chemical properties and crop and soil management. Accordingly in the present study, the high-rainfall situation has neither promoted the increase of soil-nutrient content by way of weathering nor resulted in any change in total nutrient content in soil. Probably, processes like denitrification, leaching of nutrients was higher and hence less FUE (fertilizer use efficiency) resulted in the low content in high-rainfall zones. The zones characterized by MAR between 550–1000 mm contained high content of total N and P in black soils. The relationships of total N and total P with organic carbon in various bioclimatic zones was found to be positive in this rainfall range; however, in lower-rainfall zones the relationships were negative (refer Figures. 3.1.2, 3.1.3, 3.4.2 and 3.4.3). The soil parameter, viz. clay fractions, also influenced the total N and total P, and hence organic carbon in black and red soils showed significant positive correlations (refer Figures. 3.1.7, 3.1.15, 3.4.5 and 3.4.11).

The content of nutrients in soils of arid zone were not less when compared to other zones and results indicate that there is more scope for enhancing the carbon sequestration potential in soils of this zone, than was evident from higher values of mineral N. This again reflects the greater mineralization potential of these soils despite lack of favorable soil moisture and other constraints. Under farming conditions, decline in soil fertility is difficult to measure over short intervals due to highly variable soil fertility management in space and time. However on a broad scale, land-use systems, more specifically the cropping systems, are the better units to define the changes in nutrient dynamics. In the present study, soils under systems involving horticultural crops and forests with teak and sal resulted in relatively higher content of total N and P than other available nutrients like phosphorus and sulphur, and hence exhibited highest nutrient stocks. Moreover, the soils under forests had minimum content of mineral N which could be attributed to the high soil C:N ratio, which again indicates that immobilization process dominates in the soils under this land-use. Soils under agricultural system which involved annual crops particularly legumes like pigeonpea had the next higher content of total and available nutrients. Systems such as fallow and permanent fallow had minimum content of total P and available S in soils, and consequently had low nutrient stocks. Thus the results are indicative of the fact that perennials could sequester more carbon compared to annual crops and legumes also could requester more C compared to dryland cereals. This aspect was evident from the data on nutrient stocks under these systems.

4.1 Techniques for identifying systems

The ultimate objective of the entire study was to focus on the selection of better systems under different land-use and management levels from the viewpoint of carbon sequestration. The major variable, ie, the soil organic carbon was related to total N and P which are influenced by the levels of management and land-use systems. In general, total N content in soil profile followed a similar trend to that of SOC. However, when designing methods for monitoring and estimating changes in soil nutrient stocks, consideration of the spatial and temporal heterogeneity of soil properties, general environmental conditions and management history are essential.

As carbon is only one among the several constituents of SOM, understanding the ability of soil in sequestering carbon needs more details pertaining to the elemental composition of SOM. Keeping the above considerations in view, the nutrient stocks and soil organic nutrient ratio (C:N and C:P ratios) were computed in addition to soil organic carbon for the purpose of identifying the systems. The SOC, carbon/nitrogen(C:N), carbon/phosphorus (C:P) ratios as well as nutrient stocks were considered only for the 0–30 cm soil depth which is influenced mostly by cultivation and management. The C:N ratio of black and red soils was computed for different cropping systems under different levels of management spread over various bioclimatic zones. Assuming over 90% of the total nitrogen in most soils occurs in organic forms, the C:N ratio was worked out for the soils with the above relationship from total nitrogen.

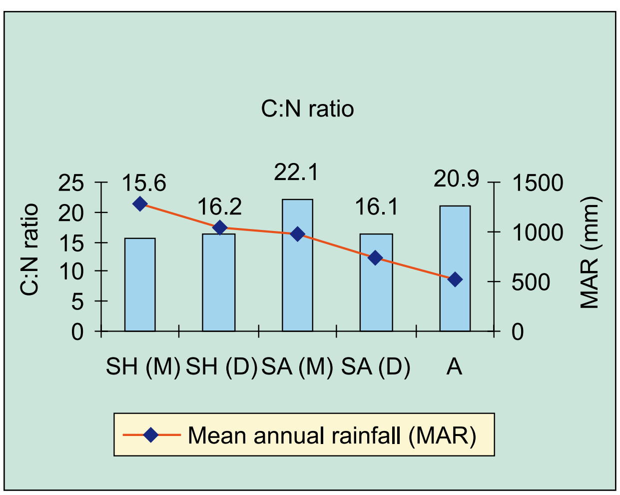
It is known that the C:N ratio generally falls within well-defined depths and varies usually from 10 to 12. But due to continuous turnover of plant residues, this narrowest ratio is seldom reached in soils under vegetation (McCalla et al. 1977). Similarly, many studies have found a significant relationship between the organic P content and the total P content of soils. In this study, the C:P ratio was worked out between organic carbon and organic phosphorus, the latter being calculated from available literature using the definite relationship that exists between total and organic phosphorus (Harrison 1987). Definite information on the limits of C:P ratio was available to define the limits of mineralization and immobilization, which was utilized in the present study in order to identify systems based on the above ratios. The limits of C:N and C:P ratios better define the process of mineralization and immobilization in soil, which in other words indicates the carbon content of soils in order to identify the systems where a wide C:N ratio was preferred. Increasing the concentration of SOM to improve the soil fertility and to sequester C involves the sequestering or immobilizing plant nutrients as well as C. In most soils the C:N ratio varies according to the climate, elevation, type of vegetation and microbial activity, and decreases with increasing depth. These factors lead to assessment of individual or integrated influence on net immobilization or net mineralization. Generally in soils which retain very low SOC, the SOM has undergone a greater degree of oxidation where the ratio between C and N decreased. In soils which were rich in SOC and where the OM has not undergone the process of decomposition, there was incidence of a high C:N ratio. Hence the above organic soil nutrient ratios are assessed for their variability due to different bioclimatic zones, land-use and soil types before going into the system identification.

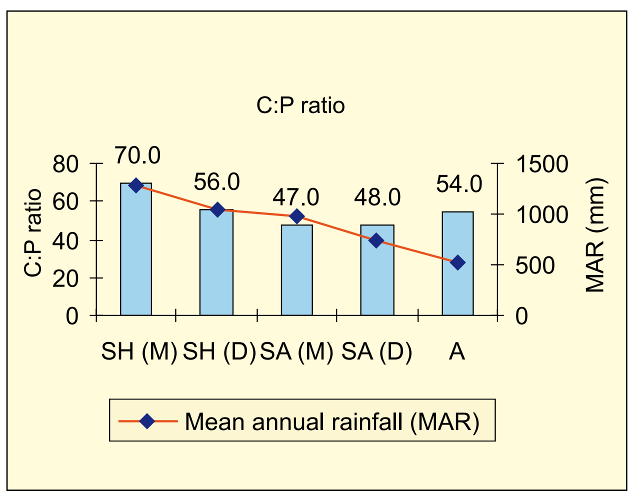
4.2 Variation in C:N and C:P ratio of soils in various bioclimatic zones

4.2.1 Black soils

Figures 4.1 and 4.2 illustrates the variation in C:N and C:P ratios of soils at 0–30 cm depth in different bioclimatic zones. It was observed that the C:N ratio varied from 16:1 and 22:1 under different zones and it was highest under semi-arid (moist) zone. Soils in the arid zone had high soil C: N ratio. The high content under semi-arid (moist) was due to the comparatively high organic carbon content and low nitrogen content. The general trend shows that with decrease in rainfall there is no considerable variation in the ratio in sub-humid zone while there was a decrease in semi-arid (dry) zone as compared to semi-arid (moist) zone.

Similarly, the values on C:P ratio of soils under various bioclimatic zones revealed that it was highest under sub-humid (moist) and lowest under semi-arid zones. The C:P ratio of arid zone was also higher. The C:P ratio showed a decreasing trend with decrease in rainfall.

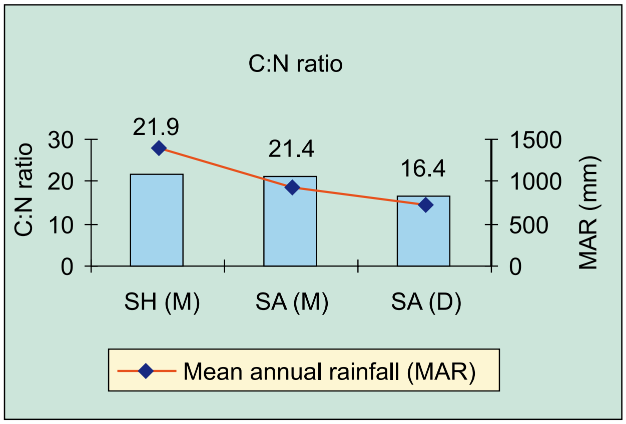


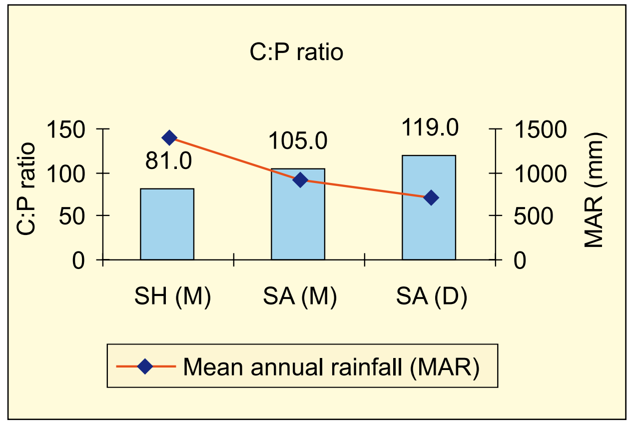


Figures 4.1 and 4.2: Variation in C:N and C:P ratios of black soils under different bioclimatic zones.

4.2.2 Red soils

Figures 4.3 and 4.4 show the relationship of C:N and C:P ratios of soils at 0–30 cm depth in various bioclimatic zones. In red soils the ratio decreased with decrease in the rainfall and the C:N ratio was the lowest in semi-arid (dry) zone. Contrary to the C:N ratio, the C:P ratio increased with decrease in rainfall and it was lowest in sub-humid (moist), which could be due to the high phosphorus content of soils in this zone.

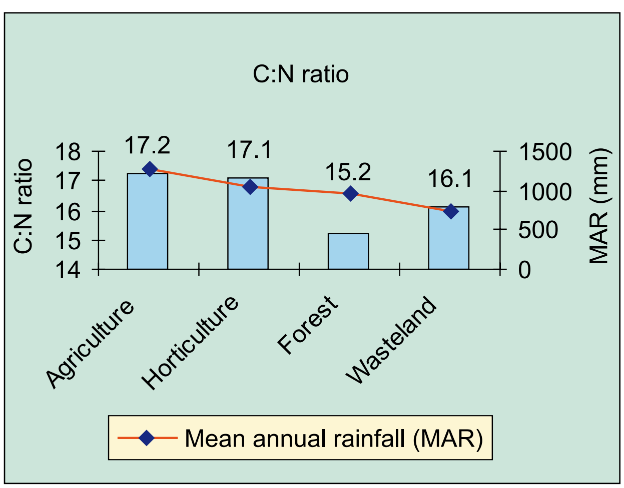


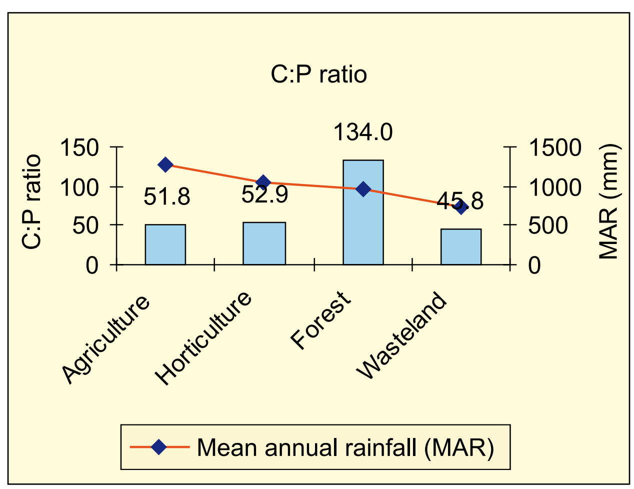


Figures 4.3 to 4.4 Variation in C:N and C:P ratios of red soils under different bioclimatic zones.

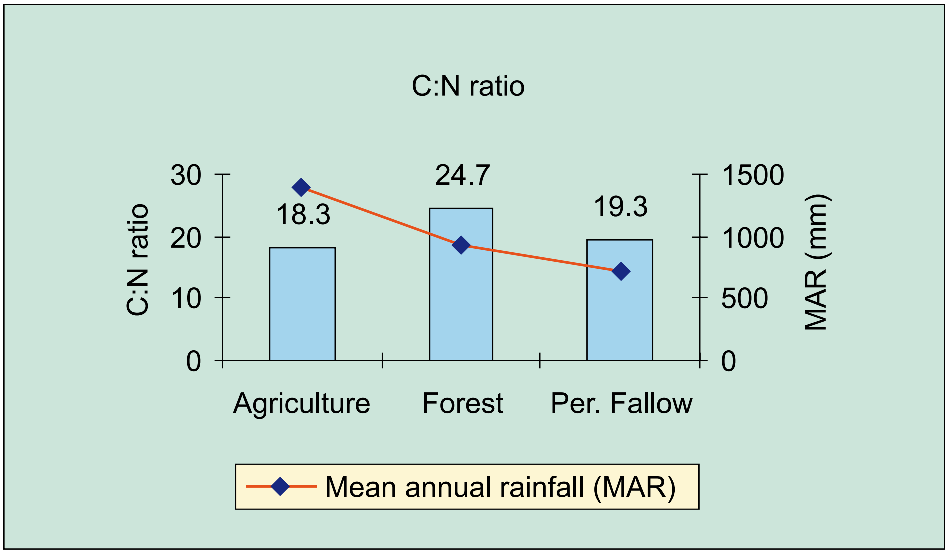
4.3 Variation in C:N and C:P ratios under different land-use

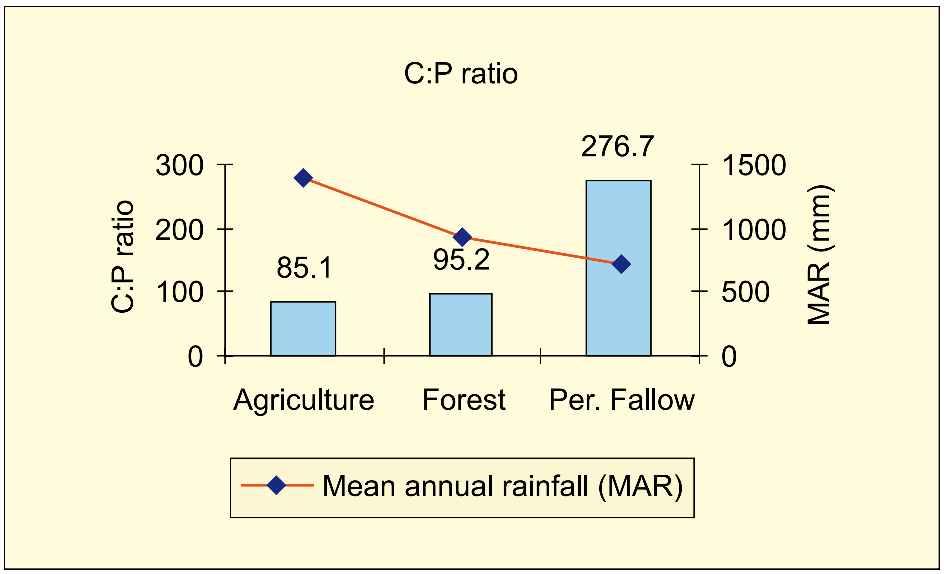
Figures 4.5 and 4.6 illustrate the variation of C:N and C:P ratios under different land usees in black soils, and Figures 4.7 and 4.8 in red soils. The agricultural system and horticultural system in black soils had high C:N ratio while forest system had a low ratio. In red soils, forest system had high C:N ratio. Similarly, the C:P ratio of black and red soil indicated high values in forest systems as compared to other systems. The importance of higher C:N and C:P ratios in relation to nutrient mineralization and release was discussed in the previous sections. This criterion was used for the identification of better systems based on the assumption that higher C:N and C:P ratios of soils distributed in different bioclimatic zones in different soil types would favor more immobilization, which in turn would lead to the storage of carbon in soils.





Figures 4.5 and 4.6 Variation in C:N and C:P ratios of black soils under different land-use systems.





Figures 4.7 and 4.8 Variation in C:N and C:P ratios of red soils under different land-use systems.

4.4 Identifying better production systems for carbon sequestration

Nitrogen content of both soil types related better with SOC and the contribution of organic P to TP was less (27–32%) in the soils of different production systems. Similar to TN content, the TN stocks were positively correlated with SOC under both soil types and hence taken into consideration for the identification of systems. In soil, the C:N ratio of 15:1 to 30:1 is assumed as a favorable condition because nitrogen needs are supplied with minimum oxidation of SOC and hence there is greater scope for sequestration of carbon the ratio is above 30:1, as found in case of a few forest systems, the nitrogen consumption is assured by soil reserves, which is not considered as a favorable condition for the growth of annual crops. Again it should be emphasized that neither the transformation processes for sequestering C nor the uptake of N, P and S by plants are 100% efficient. It is difficult to calculate N, P and S quantities to produce excellent yield and to sequester C.

The C:N ratio of soils in the present study under various systems were wider than commonly reported values (10–12) for other tropical soils. Already published literature is available explaining the wide variation in C:N ratio of surface soils of peninsular India (Malewar et al. 1998). The C:N ratio narrows following the humification process, from more than 20 in fresh OM to 8–20 in humus. During the process of microbial decomposition, the C:N ratio is reduced to the narrowest value at which C and N can exist together in soils, ie, around 10:1(Tan 1994). As the threshold minimum value is fixed at 15:1, the threshold values of SOC for black and red soils will be different due to different mean organic N contents. In the present study, the mean organic N content of black soils was 0.042% and in case of red soils it was 0.052%, which corresponds to a minimum threshold level of 0.63% and 0.78% for black and red soils, respectively. Thus within the defined range of C:N ratios, those soils having an SOC content of above values were considered along with minimum threshold values of total nitrogen stocks (Mg ha^{-1}) to arrive at better systems.

The minimum values of TN stocks were calculated from the present study with the established equation, and the values for the corresponding levels of SOC was found to be 1.95 Mg ha^{-1} for black soils and 2.30 Mg ha^{-1} for red soils (both the soils types having an average bulk density of 1.5 Mgm^{-3}). Thus the soil total N stocks of systems which was found above the minimum threshold values, are considered as better production systems. Accordingly, 24 systems are identified out of which 17 systems are under black soils and 7 under red soils. The list of identified systems in different bioclimatic zones and soil types is presented in Table 4.1 and Figure 4.9. Also, those systems which satisfied any two of the above parameters, but failed to qualify in the list of identified systems with a narrow difference in the limits, were considered as systems having scope for carbon sequestration. In these systems if the management levels are improved by way of addition of organic and inorganic inputs, the soil fertility levels will improve with respect to SOC and other soil nutrients and these will become better production systems in the near future. The list of those systems (7 systems, 6 under black and 1 under red soil) is presented in Table 4.1 and Figure 4.10. Out of the above-identified 24 systems, 14 systems were identified as viable for OC sequestration on the basis of content of SOC (Bhattacharyya et al. 2006c). Later, the number of identified systems was broadened to 22 on the basis of SOC stock per unit were (Bhattacharyya et al. 2006b).

Only P8 and P13 were not identified using these criteria. Among the above, P8 was found to have less of total nitrogen stock and P13 was found to have low SOC and TN stocks. The additional systems identified based on the three parameters viz., C:N ratio, SOC and total N stocks, are 7 under black soils (P49, P4, P50, P9, P2, P10 and P36) and 2 under red soils (P23 and P16).

4.5 Computation of Soil Carbon-Soil Nutrient Index for Identifying Systems

The relative contribution of each of the above three properties was presented in terms of soil C:N index. To delineate the better carbon-sequestering systems from poor sequestering systems, the nutrient stocks and nutrient ratio in addition to soil organic carbon in 0–30 cm depth were used as the main criteria to develop the index. The assumption being made to develop the index was that the SOC, C:N ratio as well as the total N stock of soil influences the soil carbon fertility irrespective of soil types and cropping systems. Accordingly, weightage was given for the respective values of nutrient ratios, nutrient stocks and organic carbon for each system and the index was developed by the linear scoring method, and then the additive score was taken and averaged. Based on the magnitude of the values, the respective systems were identified as better or poor with respect to carbon sequestration. In the present study, the index varied between 0.27 and 0.87 with an average of 0.57 under the various systems spread over different bioclimatic zones and soil types. Considering the importance of the above index, the variations were discussed according to soil types, bioclimatic zones, land-use and dominant crop based systems.

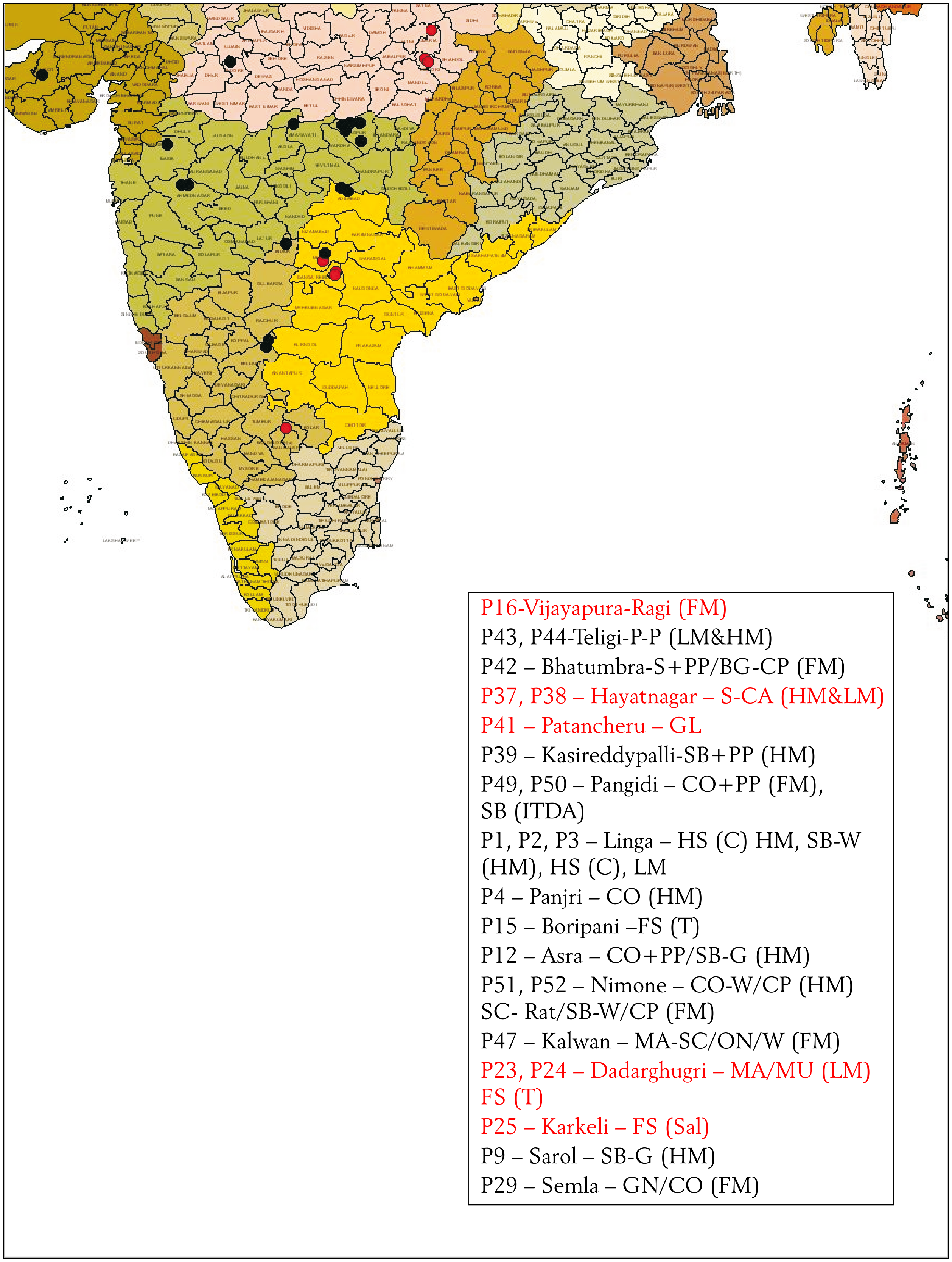


Figure 4.9 Production systems with better carbon sequestration potential identified in SAT of India.

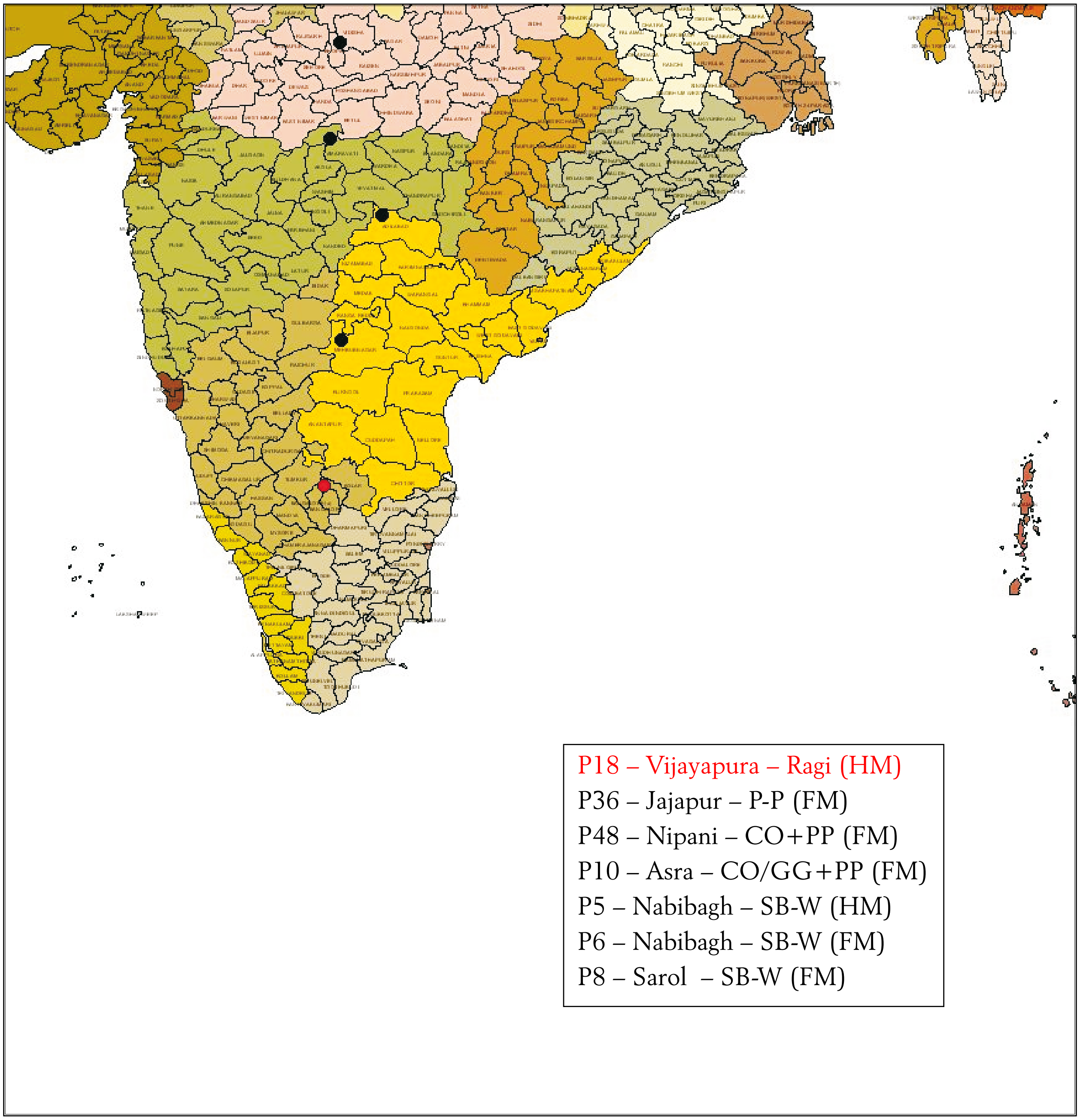


Figure 4.10 Production systems having scope for carbon sequestration in SAT of India.

Table 4.1. Soil C:N index for production systems under different bioclimatic zones and soil types upto 30 cm soil depth.

Black Soils

Sub-humid (moist)

Pedon No.	OC% 0–30 cm	N stocks $Mgha^{-1}$	Soil C:N ratio	Index	Cropping system and management level	Status
P27	0.53	2.54	10.4	0.37	P/W/MA (HM)	Not identified
P28	0.64	1.69	17.6	0.41	SB-W (FM)	Not identified
P15	0.81	2.38	15.2	0.45	Teak	Identified
P5	0.75	1.76	18.5	0.44	SB-W (HM)	Scope for improvement
P6	0.65	1.86	15.2	0.39	SB-G/W (FM)	Scope for improvement
P4	0.64	0.09	16.9	0.42	Cotton (HM)	Identified

Sub-humid (dry)

Pedon No.	OC% 0–30 cm	N stocks $Mgha^{-1}$	Soil C:N ratio	Index	Cropping system and management level	Status
P48	0.82	2.93	14.7	0.49	CO+PP/S (FM)	Scope for improvement
P49	1.05	2.33	17.3	0.51	SB+PP (FM)	Identified
P50	0.90	2.43	16.1	0.48	Soybean	Identified
P7	0.54	2.24	12.0	0.37	SB-W (HM)	Not identified
P8	0.76	1.84	19.3	0.45	SB-W (FM)	Scope for improvement
P9	0.73	2.15	15.9	0.43	SB-G (HM)	Identified
P1	0.90	2.53	17.8	0.51	Orange (HM)	Identified
P2	0.83	2.53	16.4	0.48	SB-G/W (FM)	Identified
P3	0.86	2.44	16.4	0.48	Orange (LM)	Identified

Semi-arid (moist)

Pedon No.	OC% 0–30 cm	N stocks $Mgha^{-1}$	Soil C:N ratio	Index	Cropping system and management level	Status
P42	0.88	1.90	21.0	0.49	S+PP/BG-CP (FM)	Identified
P10	0.75	1.67	24.0	0.49	CO/GG+PP (FM)	Scope for improvement
P11	0.75	1.75	21.5	0.47	SB+PP (FM)	Not identified
P12	0.72	2.12	21.7	0.52	SB-G-CO-PP (HM)	Identified

Semi-arid (dry)						
Pedon No.	OC% 0–30 cm	N stocks Mgha^{-1}	Soil C:N ratio	Index	Cropping system and management level	Status
P32	0.44	2.61	9.5	0.35	SB-W (FM I)	Not identified
P33	0.53	2.26	13.3	0.38	P-W (FM II)	Not identified
P13	0.63	1.43	23.5	0.45	CO-PP/S (LM)	Not identified
P14	0.60	1.70	18.8	0.42	CO-PP/S (HM)	Not identified
P35	0.38	1.97	11.6	0.32	S/PP+GG (FM I)	Not identified
P36	0.88	4.65	12.0	0.59	P-P (FM II)	Scope for improvement
P39	0.76	2.61	15.5	0.47	SB+PP (HM)	Identified
P40	0.48	1.90	13.5	0.35	G (TM)	Not identified
P45	0.30	1.09	13.8	0.27	PP/SF (FM)	Not identified
P46	0.84	1.76	20.7	0.47	Sorghum (LM)	Not identified
P47	0.90	2.47	17.0	0.49	MA-SC/Onion/W (FM)	Identified
P19	0.38	1.00	15.9	0.30	Sorghum	Not identified
P20	0.47	1.18	18.7	0.36	WL	Not identified
P21	0.43	1.11	17.1	0.33	Cotton (HM)	Not identified
P29	0.76	1.88	18.8	0.45	GN/CO (FM)	Identified
P43	1.03	2.61	18.4	0.54	P-P (LM)	Identified
P44	0.80	2.58	16.1	0.48	P-P (HM)	Identified

Arid						
Pedon No.	OC% 0–30 cm	N stocks Mgha^{-1}	Soil C:N ratio	Index	Cropping system and management level	Status
P30	0.36	1.19	16.1	0.32	CO/PM (FM I)	Not identified
P31	0.50	0.66	35.2	0.51	CO-PM/LS (FM II)	Not identified
P51	0.76	2.50	17.3	0.48	CO-W/CP (HM)	Identified
P52	0.76	2.19	15.0	0.43	SC-SB/W/CP (FM)	Identified

Red soils

Sub-humid (moist)						
Pedon No.	OC% 0–30 cm	N stocks Mgha^{-1}	Soil C:N ratio	Index	Cropping system and management level	Status
P23	2.10	4.44	19.2	0.82	MA-MU (LM)	Identified
P24	2.42	4.45	19.6	0.87	Teak	Identified
P25	1.09	2.12	29.8	0.64	Sal	Identified
P26	0.60	1.77	19.2	0.42	SP/Minor millet (LM)	Not identified

Semi-arid (moist)						
Pedon No.	OC% 0–30 cm	N stocks Mgha^{-1}	Soil C:N ratio	Index	Cropping system and management level	Status
P16	0.90	2.31	21.7	0.53	Finger millet (FM)	Identified
P17	0.50	1.56	15.7	0.36	Pulses	Not identified
P18	0.81	1.53	26.7	0.52	Finger millet (HM)	Scope for improvement

Semi-arid (dry)						
Pedon No.	OC% 0–30 cm	N stocks Mgha^{-1}	Soil C:N ratio	Index	Cropping system and management level	Status
P37	0.93	2.84	16.5	0.52	S-CA (HM)	Identified
P38	0.96	3.05	16.0	0.53	S-CA (LM)	Identified
P41	1.42	3.92	19.3	0.69	Grassland	Identified
P34	0.72	3.19	11.4	0.46	CA+PP (FM)	Not identified
P22	0.75	2.06	18.6	0.46	Tomato	Not identified

4.4.1 Variation of soil C:N index in different soil types

The variation of soil C:N index in different soil types is given in Figure 4.11. As discussed in the previous section, the fertility status of red soils in terms of SOC and soil nutrient stocks in majority of the pedons was higher as compared to black soils. The same trend was reflected in the index also.

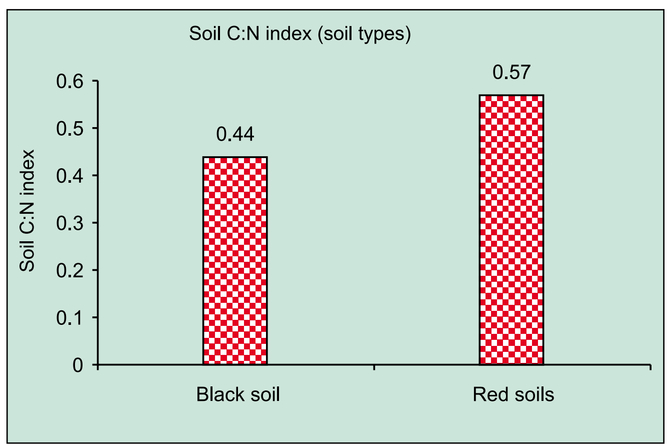
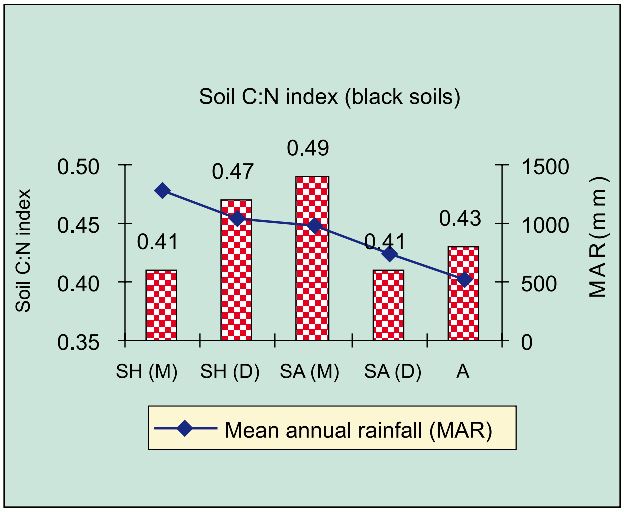


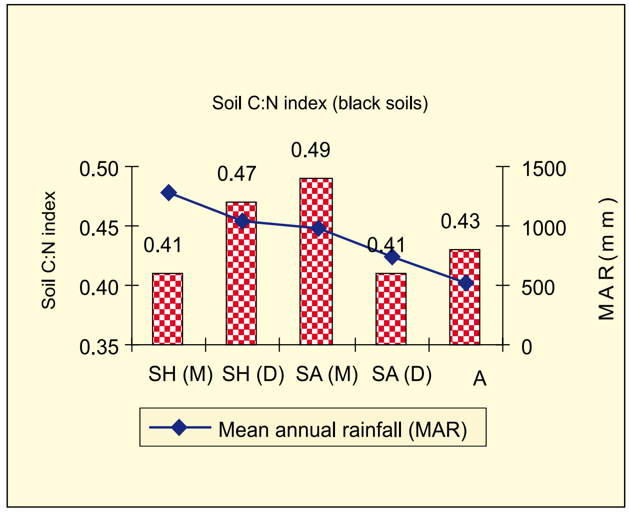
Figure 4.11 Variation of index in different soil types.

4.4.2 Variation of soil C:N index in different bioclimatic zones

The variation in the soil C:N index due to variations in bioclimatic zones in black and red soils are given in Figures 4.12 and 4.13.

From the above figures, it is observed that semi-arid (moist) zone in black soils had the highest soil C:N index while the lowest was observed in sub-humid (moist) zone. As the MAR decreased from 1200 mm to 850 mm, the index increased from 0.30 to 0.38. Thus among the zones, the semi-arid (moist) was found to sequester carbon better when compared to other zones. As explained previously, arid zones have the potential to sequester more carbon when compared to other zones, as evident from the better index. The better index among different bioclimatic zones of red soils, are evident from Figure 4.13: highest in sub-humid (moist) and least in semi-arid (moist). This again explains the influence of soil type under similar bioclimatic zones where the sub-humid (moist) and semi-arid (moist) has shown opposite trend with respect to the index. However, analysis of the index under



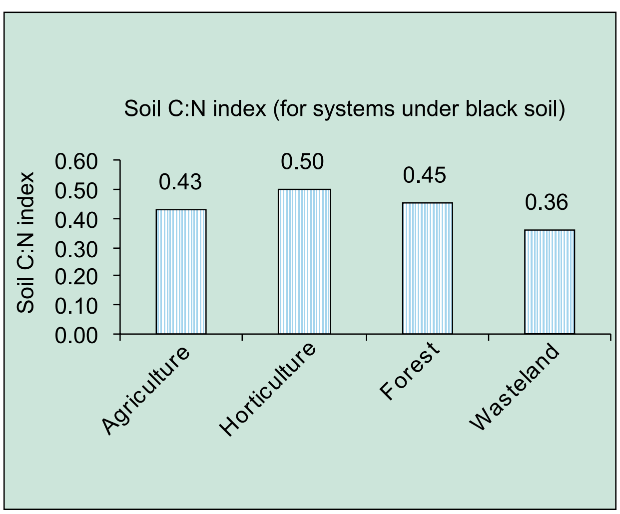


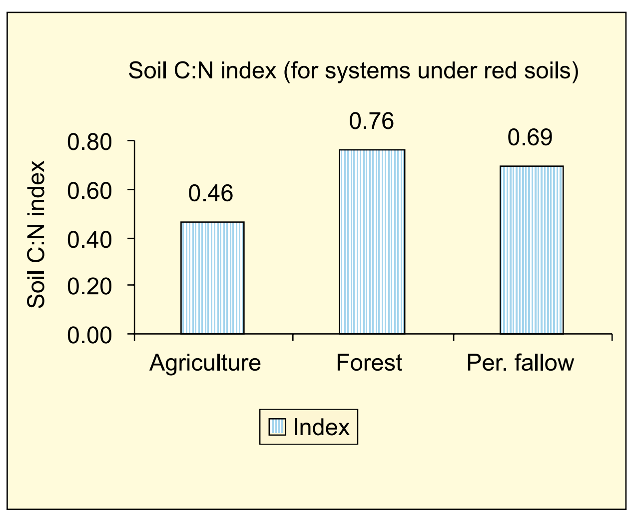
Figures 4.12 to 4.13 Variation of soil C:N: P index in different soil types under different bioclimatic zones.

different systems in the same bioclimatic zone can help to identify the better systems and which have the potential to sequester more carbon.

4.4.3 Variation of soil C:N index due to different land-use systems

The variation in soil C:N index is illustrated in Figures 4.14 and 4.15 for black and red soils, respectively. It was observed that horticulture and forest systems have better indexes as compared to agricultural system in black soils. In red soils, forest system had a better index as compared to agricultural system, which was dominated by annual crops. It could be observed that permanent fallow also had the potential to sequester carbon based on the magnitude of soil C:N index (Figure 4.15).

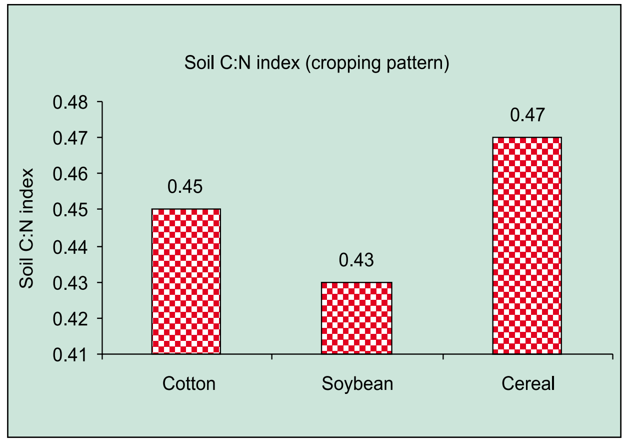




Figures 4.14 to 4.15 Variation of index in different soil types under different land-use systems.

4.4.4 Variation of soil C:N index in different dominant crop – based systems

Figure 4.16 illustrates the variation in the index with the three major crop – based systems studied. Cereal-based cropping systems are better sequesters of carbon when compared to cotton and soybean – based systems and can be promoted. In cereal-based system, sufficient organic and inorganic inputs are applied, which definitely enhance the soil organic carbon content through production of more biomass.



Figures 4.16 Variation of index in different crop based systems.

Summary and Conclusions

The project aimed at identifying farming systems that could reduce CO_2 concentration in the atmosphere and increase the stocks of soil organic carbon and other nutrients while maintaining or increasing the system's overall productivity in SAT India. Characterizing spatial variability and distribution of nutrients in soil profile in relation to site characteristics including climate, land-use, and other variables was studied in the benchmark spots. Land-use and type of vegetation were taken into account when relating soil nutrients with environmental conditions and in characterizing soil nutrients/soil nutrient stocks; and carbon to nitrogen ratio. This report had the objective of discussing the impact of various agricultural practices and the management levels adopted by the experimental stations and farmers on soil nutrient dynamics and its relationship with SOC in various land-uses of SAT. This was analyzed with the aim of identifying potential carbon – sequestering production systems in the SAT benchmark sites:

- Assess the dynamics of soil nutrients and stocks and the effects of land-use and management levels in different bioclimatic zones of black and red soils, which total nitrogen (TN), total phosphorus (TP), mineral N (MN), available phosphorus (AP) and available sulphur S (AS), include and their relationships with soil organic carbon
- Identify better production system(s) that sequester more soil organic carbon and sustain the system.

The study area covered 28 benchmark (BM) spots, 21 out of which were on black soils and 7 on red soils, covering an area of 15.29 m ha and 6.34 m ha, respectively. Soils were sampled from the above mentioned benchmark sites/pedons during the year 2000–03 and processed for chemical analysis. Computation of soil nutrient stocks was done, and total and available nutrient content was calculated in terms of Tg units (Tg = 10^{12} g).

In the present study, irrespective of bioclimatic zones, land-use under horticultural (P1, P3) and agricultural systems (pedons P27, P49, P32, P36, P47, P43, P52) in general, and paddy systems in particular, had maximum content of total N. In these systems, soil-texture improvement by way of practices like application of tank silt, practices for harboring more organic carbon should be promoted in red soils.

The zones characterized by MAR between 550–1000 mm contained high content of total N and P in black soils. The relationships of total N and total P with organic carbon in various bioclimatic zones was found to be positive in this rainfall range. However in lower-rainfall zones the relationships were negative. The soil parameter, viz. clay fractions, also influenced the total N and total P, and hence organic carbon in black and red soils showed significant positive correlations.

Soils under systems involving horticultural crops and forests with teak and sal had relatively higher content of total N and P and other available nutrients like phosphorus and sulphur, and hence exhibited highest nutrient stocks. Moreover, the soils under forests had minimum content of mineral N which could be attributed to high soil C:N ratio, which again indicates that immobilization process dominates in the soils under forest system. Soils under agricultural system, which involved annual crops, had higher content of total and available nutrients. Systems such as fallow, permanent fallow had the minimum content of total P and available S in soils, and consequently had low nutrient stocks. Thus the results are indicative of the fact that perennials could sequester carbon better as compared to annual crops. This aspect was evident from the data on nutrient stocks under these systems.

Techniques for identifying systems

To focus on the selection of better systems under different land-use and management levels from the viewpoint of carbon sequestration, the important variable, ie, the soil organic carbon was related with total N and P which are influenced by the levels of management and land-use systems. In general, total N content in soil profile followed a similar trend to that of SOC. The nutrient stocks and soil organic nutrient ratio (carbon/nitrogen (C:N), and carbon/phosphorus (C:P)) were computed in addition to SOC for the purpose of identifying the systems

Variation in C:N and C:P ratios of soils in various bioclimatic zones

It was observed that the C:N ratio varied from 16:1 and 22:1 under different zones and it was highest under semi-arid (moist) zones in black soils. It could be observed that the soils representing arid zone had high soil C:N ratio due to the high C:N ratio of Sokhda series (P31). The general trend showed that with decrease in rainfall there was no considerable variation in the ratio in sub-humid zones while there was a decrease in semi-arid (dry) zones as compared to semi-arid (moist) zones. Similarly, the values off C:P ratio of soils under various bioclimatic zones revealed that it was highest under sub-humid (moist), followed by arid zone and lowest under semi-arid zones. The C:P ratio showed a decreasing trend with decrease in rainfall. In red soils it was observed that the ratio decreased with a decrease in the rainfall and accordingly the C:N ratio was the lowest in semi-arid (dry) zones.

Variation in C:N and C:P ratios under different land-use systems

It was observed that the agricultural and horticultural systems in black soils had high C:N ratios while the forest system had low values. In red soils, the forest system was found to contain high C:N ratio. Similarly, the C:P ratios of black and red soil indicated high values in forest systems as compared to other systems.

Identifying better production systems for carbon sequestration

Nitrogen content of both soil types was better correlated with SOC and the contribution of organic P to TP was less (27–32%) in the soils of different production systems. Similar to TN content, the

TN stocks were also positively correlated with SOC under both soil types and hence taken into consideration for the identification of systems. In soil, the C:N ratio of 15:1 to 30:1 is assumed as favorable condition because the nitrogen needs are supplied with minimum oxidation of SOC and hence there is greater scope for the sequestration of carbon. Where the ratio is above 30:1 as found in case of few forest systems, the nitrogen consumption is assured by soil reserves, which is not considered as a favorable condition for the growth of annual crops. Again it should be emphasized that neither the transformation processes for sequestering C nor the uptake of N, P and S by plants are 100% efficient. It is difficult to calculate N, P and S quantities to produce excellent yield and to sequester C.

The soil C:N ratios of study soils under various systems were wider than commonly accepted values (10–12) reported for other tropical soils. The mean organic N content of black soils was 0.042% and in case of red soils it was 0.052%, which corresponds to a minimum threshold level of 0.63% and 0.78% for black and red soils, respectively. Thus within the defined range of C:N ratios, those soils having an SOC content of above values were considered along with minimum threshold values of total nitrogen stocks (Mg ha^{-1}) to arrive at better systems. The minimum values of TN stocks were calculated with the established equation and the values for the corresponding levels of SOC were found to be 1.95 Mg ha^{-1} for black soils and 2.30 Mg ha^{-1} for red soils (both the soils types having an average bulk density of 1.5 Mgm^{-3}). Thus the soil total N stocks of systems that were found above the minimum threshold values are considered as better production systems. Accordingly, 24 systems are identified out of which 17 systems are under black soils and 7 under red soils. In these systems, if the management levels improve, there is addition of organic and inorganic inputs, the soil fertility levels will also improve with respect to SOC and other soil nutrients, and they will become better production systems in the near future. The criteria for their identification are systems with high SOC, SOC stock per unit area and lower content of SIC, along with soil bulk density.

Soil C:N index for identifying systems

To delineate the better carbon – sequestering systems from poor sequestering systems, the nutrient stocks and nutrient ratio in addition to soil organic carbon upto 0–30 cm depth were used as the main criteria to develop the soil C:N index. In the present study, the index varied between 0.27 and 0.87 with an average of 0.57 under the various systems spread over different bioclimatic zones and soil types. Considering the importance of above index, the variation was discussed according to soil types, bioclimatic zones, land-use and dominant crop – based systems.

The variation of soil C:N index in different soil types showed that, the fertility status of red soils in terms of SOC and soil nutrient stocks in majority of the pedons was higher as compared to black soils. The same trend was reflected in the index also.

The variation in the soil C:N index due to bioclimatic zones in black and red soils, showed that semi-arid (moist) zone in black soils had the highest soil C:N index while the lowest was observed in sub-humid (moist) zone. As the MAR decreased from 1200 mm to 850 mm, the index increased from 0.30 to 0.38. Thus among the zones, the semi-arid (moist) was found to sequester carbon better when compared to other zones. As explained previously, the arid zone also has the potential to sequester more carbon as compared to other zones.

Land-use systems such as horticultural and forest systems had better C:N index as compared to agricultural system in black soils. In red soils, forest system had better C:N index as compared to agricultural system dominated by annual crops. It could be observed that the permanent fallow also had the potential to sequester carbon based on the magnitude of soil C:N index.

The variation in the soil C:N index with the three major crop – based systems studied above showed that cereal – based cropping systems sequester more carbon when compared to cotton and soybean – based systems and can be promoted.

Conclusions

The following conclusions are drawn from the present investigation on 28 benchmark spots in the semi-arid tropical, India.

1. The relationship of SOC content with that of total N content of soils in SAT region was found to be significant. The presence of more clay content was found to improved the SOC content in red soils.

2. High levels of management improved the soil fertility in black and red soils through increase in SOC and major nutrients.

3. The soil C:N index varied widely among different soil types and systems. Low value of index indicates poor fertility due to low SOC, low C:N ratio (more mineralization) and low stocks of total nitrogen, and high value indicate better fertility condition of the soil.

4. The index was high for red soils (as compared to black soils) in sub-humid (moist) zone. The black soil under semi-arid (moist) zone was found to have high value of index as compared to other zones.

5. The index was found maximum for horticulture (0.50) and forest (0.45) systems in case of black soils and permanent fallow (0.69) and forest system (0.76) in red soils.

6. Among the annual crops, cereal – based cropping systems was found to have high value of index as compared to cotton and soybean – based cropping system though more or less same index was observed in all the three dominant crop – based systems.

7. The following were the preferred/identified systems as given by pedon number for the purpose of carbon sequestration potential in SAT soils.

   SH (M) – P4, P15, P23, P24, P25
   SH (D) – P1, P2, P3, P9, P49, P50
   SA (M) – P12, P16, P42
   SA (D) – P29, P37, P38, P39, P41, P43, P44, P47
   A – P51, P52.

8. The following systems have considerable scope so as to become better systems in the near future by further improving the management practices.

   SH (M) – P5, P6; SH (D) – P8, P48; SA (M) – P10; P 18, and SA (D) – P36.

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About CRIDA

The Central Research Institute for Dryland Agriculture (CRIDA) started functioning as a full-fledged research institute under ICAR in 1985 with its headquarters at Hyderabad. It is involved in basic and strategic research in dryland agriculture in order to develop appropriate technologies for efficient management and utilization of natural resources and to improve productivity in drylands. The major research focus of this institute includes resource characterization, rainwater management, integrated nutrient management, crops and cropping systems, alternate land-use systems, energy management, and socio-economic issues relevant to dryland agriculture. Some of the important contributions made by the institute are: (i) agro-climatic characterization and delineation of areas suitable for monocropping, intercropping and double cropping, (ii) strategies for agricultural drought management, contingency planning and mid-season corrections, (iii) location-specific technologies for soil and rainwater management, integrated nutrient management and integrated watershed management, (iv) development of alternate land-use systems for rehabilitation of marginal lands, and (v) low-cost labor and energy-saving implements for carrying out timely agricultural operations. CRIDA also backstops dryland agricultural research through the All India Coordinated Research Project for Dryland Agriculture (AICRPDA) with a network of 22 centers and the All India Coordinated Research Project on Agrometeorology (AICRPAM) with a network of 25 centers spread across the country. The institute is recognized as a premier research institute for providing technical guidance and policy support in the area of rainfed agriculture and watershed development projects in the country. CRIDA also received the ICAR's best institute award for the year 1995 for its excellent services. The institute is also actively engaged in conducting training programs besides undertaking contract research and contract services. This institute was also entrusted with the work of planning and coordinating research in the National Agricultural Technology Project (NATP) on production system mode under the rainfed agro-ecosystem.

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The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) is a nonprofit, non-political organization that does innovative agricultural research and capacity building for sustainable development with a wide array of partners across the globe. ICRISAT's mission is to help empower 600 million poor people to overcome hunger, poverty and a degraded environment in the dry tropics through better agriculture. ICRISAT belongs to the Alliance of Future Harvest Centers of the Consultative Group on International Agricultural Research (CGIAR).

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