

**SOIL FERTILITY STATUS OF A PART OF GLBC COMMAND AREA
USING GIS**

N. K. BINITHA

**DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY
COLLEGE OF AGRICULTURE, DHARWAD
UNIVERSITY OF AGRICULTURAL SCIENCES,
DHARWAD – 580 005**

SEPTEMBER, 2002

SOIL FERTILITY STATUS OF A PART OF GLBC COMMAND AREA USING GIS

Thesis submitted to the
University of Agricultural Sciences, Dharwad
in partial fulfillment of the requirements for the
Degree of

Master of Science (Agriculture)

In

SOIL SCIENCE AND AGRICULTURAL CHEMISTRY

By

N. K. BINITHA

DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY
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UNIVERSITY OF AGRICULTURAL SCIENCES,
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CERTIFICATE

This is to certify that the thesis entitled "SOIL FERTILITY STATUS OF A PART OF GLBC COMMAND AREA USING GIS" submitted by Miss. N. K. BINITHA, for the degree of MASTER OF SCIENCE (AGRICULTURE) in SOIL SCIENCE AND AGRICULTURAL CHEMISTRY, to the University of Agricultural Sciences, Dharwad is a record of research work done by her during the period of her study in this university under my guidance and the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar titles.

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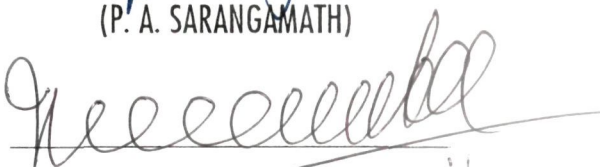
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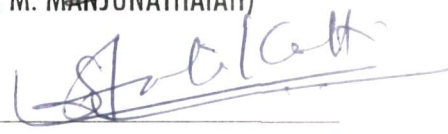

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Members : 1. 
(P. A. SARANGAMATH)

2. 
(H. M. MANJUNATHAIAH)

3. 
(S. I. HALIKATTI)

ACKNOWLEDGEMENT

With Soul Searching memories...

No words would ever sustain the appreciation for eager involvement and unceasing encouragement at every stage of investigation, extended by **Dr. G. S. Dasog**, Professor (Soil Science and Agricultural Chemistry), University of Agricultural Sciences, Dharwad and the Chairman of my Advisory Committee. I must confess that it has been a rare privilege for me to work under his guidance.

As the novice runs, I greatly acknowledge to the other benevolent faces of my advisory committee members **Dr. P.A. Sarangamath**, Professor and Head, Department of Soil Science and Agricultural Chemistry, **Dr. H. M. Manjunathaiah**, Professor of Soil Science and Agricultural Chemistry, Directorate of Research, University of Agricultural Sciences, Dharwad and **Dr. S. I. Halikatti**, Associate Professor, Department of Agronomy, University of Agricultural Sciences, Dharwad for their fruitful advises and constructive criticism.

I am grateful to my teachers Dr. V. S. Doddamani, Dr. B. Basavaraj, Dr. T. D. Bharamagoudar, Dr. H. T. Channal, Mr. C. M. Poleshi, Dr. B. M. Raddar, Dr. B. M. Hirekurabar, Dr. S. K. Gali, Dr. N. S. Hebsur and Dr. P. L. Patil for their excellent teaching and cooperation extended to me during the course of my study and research.

I have no words to express my heartfelt love and affection to my father Gangadharan, mother Ramadevi and brother Binil.

My words of gratitude are boundless towards the members of GJS family: Kiran sir, Mr. Harikrishna, Mr. Ashok Kumar, Shamsu and Mini, my SAC friends : Venu, Ananthu, Chandru, Manju, Mohan, Nataraj, Shambanna, Satheesh, Anand Naik, Tamangale, Jailhav, Harish and Ravi..

I wish to express my heartfelt thanks to Mr. Renuka Prasanna, who stood by me whenever, I leaned upon for any kind of help.

I wish to express my sincere thanks to my friends Jayanthi, Hanumanthappa, Jincy and Serene. I also like to recall such moments of mine with hostel mates Smitha, Manu, Sangeeta, Amina, Nisha, Jyothi didi, Bharati, Yogi, Arathi, Manju, Thania, sibi, Deepa and Vineetha.

*I am very much thankful to **MR. ARJUN (ARJUN COMPUTERS)**, for their neat and timely typing of this manuscript.*

.....and any omission in this short manuscript doesn't mean lack of gratitude.

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SEPTEMBER, 2002


(N. K. BINITHA)

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Introduction

I. INTRODUCTION

India has witnessed a tremendous rise in food grain production from about 51 million tonnes in 1950 to 200 million tonnes by 2002. When we evaluate factors that have contributed to our overwhelming success in green revolution, we can observe that it is mainly due to expansion of area under cultivation, intensification of agriculture, irrigation, use of high yielding varieties, increased use of synthetic fertilizers and plant protection chemicals.

In India the land resources available for agriculture are shrinking. Our aim of optimizing the utilization of land resources with intensification of agriculture resulted either in the fast depletion of nutrients or occasionally in their accumulation. It is therefore important to monitor the fertility status of soil from time to time with a view to monitor the soil health. Hence, geo-referenced information on the location, extent, quality of land and display of spatial data is a must.

In North Karnataka black cotton soils are dominant and agriculture is literally a gamble with monsoon. Irrigation projects like Tungabhadra, Upper Krishna and Ghataprabha have however, ushered in a new era of intensive agriculture.

The Ghataprabha irrigation project is situated in Belgaum district of North Karnataka expanding irrigation facilities to 19 taluks of Belgaum, Bijapur and Dharwad districts of the state.

There is an overwhelming need to manage and conserve the natural resource base with adoption of appropriate technologies that are economically viable, socially acceptable and environmentally non-degrading in all aspects.

It is alarming to discover the fact that the irrigated areas which have substantially contributed towards achieving the goal of self-reliance in food grain production are now facing serious problem like rise in ground water table, soil salinization, rapid nutrient depletion *etc.*

Geographic information system (GIS) is defined as a powerful set of tool for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world (Burrough and McDonnell, 1998).

Precision agriculture (site-specific farming) envisages the use of GIS along with the other hi-tech facilities like GPS (Global Positioning System) and RS (Remote Sensing). According to Semay *et al.* (1998) GIS helps the farmer to identify the right input at the right time in the right amount, which not only avoid wastage of inputs but also reduce pollution due to excessive use of inputs.

In agriculture, GIS in conjunction with remote sensing can be employed for application like identifying potential crop producing areas, watershed development, land use planning etc. GIS has also been widely used in producing digital maps (Nair *et al.*, 1996). GIS can also be employed in irrigation impact assessment and water management (Dadhwal, 1994).

GIS can be used in producing a soil fertility map of an area, which will help in formulating balanced fertilizer recommendation and to understand the status of soil fertility spatially and temporally. Thus, GIS can be employed in various spheres of agriculture.

In this context, the assessment of fertility status of Ghataprabha command area soils which are being intensively cultivated with high yielding crops like sugarcane, maize, wheat and cotton are carried out using GIS with the following objectives :

1. To evaluate the status of N, P, K, Ca, Mg and S as affected by the different physiographic units using GIS and
2. To prepare the soil fertility map of a portion of GLBC command area showing the distribution of nutrients.

Review of Literature

II. REVIEW OF LITERATURE

Overexploitation of natural resources to meet the food requirement of the enormously growing population has resulted in decreased productivity of cultivated lands. Hence, periodic monitoring of soil fertility status has become the prime need of the hour. GIS technology is rapidly becoming a standard tool pertaining to management of natural resources. This chapter deals with relevant review of literature pertaining the capability of GIS technology to assist decision-makers by indicating various alternatives in development and conservation planning.

2.1 FERTILITY STATUS OF SOILS

Monem *et al.* (1990) assessed the soil fertility status of Chaouia by collecting soil samples from 25 mapped sites and a site in phosphate mining area. They observed that most of the samples were deficient in N and only a small percentage was deficient in P and K.

Park (1992) suggested that improved fertilizer recommendations must be developed based on soil fertility and the amount of nutrients removed by each crop (nutrient balance model). He cautioned that the use of high analysis complex fertilizers should be in a form containing low P and K with Mg and slow release N for improved soil management and sustainable agriculture.

Divakar *et al.* (1993) analysed 3283 soil samples representing 10 horticultural areas in Tari-Bhabar region for pH and available N, P and K. The soils were alkaline in reaction. The available N was low in three blocks and high in one block. The status of available P was low in all the ten blocks. The level of K was low in eight blocks and medium in the other two blocks.

Singh and Ghosh (1995) reported that early establishment of rice and wheat and higher NPK application increased N, P and K uptake by both crops. Organic carbon and available N, P and K content in the soil increased with high fertilizer rates.

Devarajan and Oblisami (1995) recommended effluent irrigation as it significantly increased the available N, P, K, Ca, Mg and micronutrient contents, soil pH, EC and organic matter content in soil.

Divakar *et al.* (1989) assessed soil fertility status of five blocks of hilly tract representing the horticultural area in Nainital region of UP and found that all soils were slightly acidic to alkaline. Available N was high but available P and K was low in all the soils tested.

Adhikary *et al.* (1991) studied the residual effects of maize-legume intercropping on fertility status in Chotanagpur plateau and reported that maize plus groundnut were the best

combination which increased soil organic carbon content and had no adverse effects on N, P and K contents.

* Gaikwad *et al.* (1994) indicated that rotation of sorghum with safflower on medium black soil of Maharashtra increased organic carbon while soil pH and EC remained same, available P and K showed depletion due to cropping in comparison with the initial status.

* Kaushal *et al.* (1997) studied six soil profiles in the temperate zone of the Himalayan *C. deodara* dry coniferous forest ecosystem of Himachal Pradesh for their physico-chemical properties. They reported that the soils were normal in reaction (pH ranged from 6.3 to 8.2), high in organic carbon, available P and K, low to medium in available N, medium to high in $\text{SO}_4\text{-S}$, high in availability of Na, Ca, Mg, Fe and Mn contents and low to medium in Zn and Cu supply.

Vasudevan *et al.* (1997) evaluated the nutrient status of Kanjumali hills in Tamil Nadu and showed that the soils were neutral in pH, 69 per cent of the samples analysed were low in N, all were low in P and 58 per cent were low in K while the soils were rich in Cu, Mn and Fe and the physical properties of the soils were optimum for crop production.

Peter *et al.* (1998) assessed soil fertility status of entire Zambia by collecting 1152 soil samples from fields under different crops and analysis for chemical properties showed

that except EC, all soil test parameters assessed were highest in maize fields.

Asadu and Nweke (1998) assessed the soil fertility status of Cassava growing soils in Tanzania to identify factors responsible for yield variation and observed that climate and altitude influenced eleven soil properties. Human population density and Cassava mixture influenced the particle size distribution, total N, OM and exchangeable acidity. The soils of the non-humid and low altitude zones were on an average more fertile than those of the sub-humid and mid-altitude zones.

Elghafour *et al.* (1993) evaluated soil fertility status of clayey soils of six soil profiles representing EI-Gemmeija Experimental Station, Egypt as affected by different irrigation systems via surface, sprinkler and drip system. They found that the values of available P, K and organic matter contents were negatively correlated with different irrigation systems. Nitrogen was significantly negatively correlated with sprinkler and surface irrigation systems and not with drip system. The surface layer of the soil contained the highest available N, P, K and organic matter content with a tendency to decrease as soil depth increased.

Vijay Kumar *et al.* (1995) reported that three years of cropping involving cotton-wheat fallow, wheat, cluster bean, wheat systems decreased N in soil by six to 30 kg per ha

except in cotton fallow cropping system. Similarly soil P also decreased under all the systems by four to 21.4 kg per ha.

Gately (1996) studied the soil fertility status of rural environment protection scheme (REPS) farm and indicated that 22 per cent and 17 per cent of the soils were deficient in P and K, respectively.

Shivaprasad *et al.* (1998) mapped seven soil profiles at phase level into 17 mapping units. Available nitrogen was high, available phosphorus was medium to low and available potassium was medium to high.

Sarkar *et al.* (1997) surveyed six districts of Kerala covering the toposheets 58B/9, 58B/10, 58C/11 and 58D/14 on 1:50,000 scale and correlated the soils at soil series level and mapped as association of soil series. The soil samples of master profiles of different soil series, the surface sample of the grid observations at one kilometer interval and surface (0-30 cm) and sub-surface samples (30-60 cm) of grid observation at five kilometer intervals were analysed for different physical and chemical properties to classify the soils as per soil Taxonomy and to evaluate the fertility status of the soils for assessing suitability of rubber plantations.

Miura and Badayos (1999) evaluated the regional fertility characteristics of Philippines low land soils and identified the factors determining their productivity for rice cultivation. Soil chemical characters of 52 soil sample were considered. By factor analysis four factors were extracted representing organic matter status, available K, sulphur status and soil P status. The score of these four fertility components computed for each used with a differential global positioning sensor on a Case IH Cotton picker of map yields for input into a GIS database. Yield crop, soil maps and soil fertility maps were used with GCW to develop a control tape, which could determine spatially variable rate application of seed, fertilizers and other inputs for first year experiment in summer of 1997. Case IH machinery with control computers, DGPS sensors and variable rate application equipment use information generated by GCW and crop view to carry out the above operation.

Gilmour *et al.* (2001) conducted grid sampling for determining whether any relation existed between rice and soybean yields and routine soil test data obtained from the same location as yield sample. Rice yield in 1998 was measured for 46 per cent of demonstration farm (DF) and averaged to 139 BU/acre and in 1999 for 36 per cent of DF and averaged to 136 BU/acre. Soybean yield was measured for 54 per cent of DF and

averaged to 27 BU/acre. Soil pH varied from 5.5-8 over the three crop per year combination. Soybean showed slight yield increase with slight pH increase. Soil test value for P ranged from 22-100 lb/acre, but did not cause any yield reduction. Soil test value for K ranged from 125-500 lb/acre. Soybean yields decreased with increase in K value above 150 lb/acre.

Finck and Venkateswarlu (1982) reported that the Vertisols are low in humus and deficit in available nitrogen. They also reported that these soils are fairly well supplied with phosphorus for moderate yields. Potassium, secondary nutrients (S, Ca and Mg), and micronutrients except zinc are well supplied.

Patel *et al.* (1983) reported that soils of the foot hills contained highest amount of nitrogen and the soils coastal alluvium were remarkably rich in potassium status.

2.2 FERTILITY STATUS OF SOILS USING GIS

Bober *et al.* (1996) identified land areas that were highly susceptible to traffic and tillage induced soil compaction of Northern Ontario Canada based on mechanical properties and their use for intensive row crop production under local climatic conditions. Spatial information on the distribution of various crops in relation to the major soil association was acquired

through an integrated approach involving digital image analysis and GIS. Error matrices showed that the user's accuracy of the crop cover classification at the field levels were more than 80 per cent for all major crop types. The soil associations most vulnerable to compaction where row-crops dominated included 75 km² of medium textured soils i.e., silty clay loam fills were identified as being at risk.

Sun-Bo *et al.* (1995) evaluated soil fertility status in the hilly and the mountainous region of southwestern China. The 11 indices of the Second National Soil General Survey were divided into two groups representing, separately status of soil nutrients and environments of nutrient supply including soil organic matter content, total N, total P₂O₅, total K₂O, available P₂O₅, available K₂O, pH, CEC, clay, silt-clay ratio and thickness of epipedon. Two types of membership functions of these indices: S-type and parabola type was developed based on their effects on plants. The values of the functions were calculated through factor analysis of these values of these with software (STAT GRAPHICS), weight values of these indices were decided. The integrated fertility index was calculated based on addition-multiplication principle. A comprehensive soil fertility map drawn with ILWIS software for this region depicted that soils with high, middle and low fertility covered 25.8, 40.8 and 33.8 per cent, respectively. The principal reasons affecting the full

utilization of soil fertility was low fertilizer input and soil erosion.

Raupenstrauch *et al.* (1998) used satellite remote sensing data to detect crop rotation and changes in land use system. Annual monitoring and crop classification was used to calculate nutrient balance in field level in relation to landscape properties and reported that satellite remote sensing can improve risk assessment of large regions when integrated with a balance model using GIS.

Shivaprasad *et al.* (1998) assessed the soil fertility status of Karnataka by collecting the soil samples from 1906 grid points all over the state. The soils were analysed for pH, EC, organic carbon, available phosphorus and available potassium. The data was used to prepare nutrient status maps for individual nutrients using GIS. The Western Ghats area, Coastal Plain and Malnad areas were high in available nitrogen while the area under irrigation and the hilly areas were medium in nitrogen and the rest of the area was low in nitrogen. With respect to available P, 86% of the area was low and 17% was high. The available potassium content was high in majority of the soils except coastal plains and Western Ghats where it was low.

Schreier *et al.* (1998) reported that red soils of Nepal had higher P sorption capability than the non-red soils with hue of

7.5YR to 10YR and the Al content was the best predictive variable for P sorption using a factorial design and GIS overlay technique. A phosphorus sorption map for the case study watershed was produced. The results were used for determining where agricultural intensification with chemical fertilizers application is most effective. Results showed that red soils were highly deficient in P and that management influenced P sorption capacity as Al content decreased and Fe increased in these soils on irrigation.

Hu-Yueming *et al.* (1999) proposed a system for classification and nomenclature of Chinese red soils based on GIS data and classified the red soils into 84 types and the area distribution of each red soil type was calculated using FoxPro database.

Zhou-Huizhen *et al.* (1999) employed GIS to set up a dynamic monitoring system for the catchment of Tai lake, China by choosing two temporal (1984 and 1994) sets of information on land use, soil fertility, soil and water resources as the database. The results showed that the farm land resources and the farm land per capita were decreasing and environment of soil and water surface were suffering from industrial and fertilizer pollution as application of large quantity of chemical fertilizers to soil resulted in N, P, K imbalance.

Heiniger (1999) employed new techniques like differential global positioning system and GIS to manage the variability in soil properties and the micro-environment within a field by providing information about where variability occurs and the patterns that exist in crop and soil properties. Combination of variable rate application systems, precision soil sampling and remote sensing could help in direct fertilizer, herbicide and pesticide application to only those regions of the field that require soil amendments which could result in less chemical use and improved crop performance.

Christiaena *et al.* (1996) employed GIS framework for assessing the regional environmental impact of nitrogen fertilizer use in terms of nitrate leaching. To identify the maximum allowed fertilizer dressing as a function of the soil-crop system, a process based model, simulating the fate of nitrogen in this continuum at this point scale and a GIS integrating the point model data at the regional scale were combined. The GIS extracted the necessary model input data from the available digitized soil map and the soil profile databases.

Cox *et al.* (1999) employed direct mass measurement technique for sugarcane yield mapping using ARC/view general purpose GIS package. The resultant yield map for a case study map (in Queensland) displayed yield variations from 70-220 tonnes per ha. A directed soil sampling regime was

implemented based on yield maps and other soil relation maps. The results of soil tests indicated strong negative correlation of crop yield with Na and Mg content of soils.

Puri *et al.* (1999) conducted long term research in South East coastal plains and installed yield monitors in three combined Duplin and Samson countess for data collection from 900 ha of wheat and 120 ha of rye followed by 1500 ha of maize and similar area of soybean. Preliminary data were processed in Vendoi's yield mapping software and aggregated into ARC/INFO GIS.

Hutchenson *et al.* (1999) stratified quercus forest plots into three soil moisture classes with a GIS derived integrated moisture index (IMI). In addition to the IMI, environmental data matrix included eight soil and three overstorey variables. Cononiesl correspondence analysis (CCA) indicated that variation in understorey species competition was most strongly related to topographic variation in predicted moisture (IMI) N mineralization, nitrification rate and soil pH. Strong species richness – N mineralization correlations indicated an important link between below ground process and above ground biodiversity. Because N availability was a strong correlate to vegetation patterns at a good scale. Results suggested that increasing rate of atmospheric N depletion in this region could have impact on understorey vegetation dynamics.

Gillingham *et al.* (1999) employed geographical positioning system and aircraft technology to vary fertilizer application rate along a flight path. According to pre-determined recommendation and through links to a soil type, slope and aspect related factors which govern pasture production potential compared with uniform fertilizer application. Pastures on annual productivity and economic returns was examined for three contrasting hill farm situations using a combination of trial results and a Ag research PKS lime programme. Results showed that for a farm with low soil P status, stocking rates could be increased by 0.5 t per ha and economic returns by 7.5 per cent by differential rather than uniform fertilizer application. In a summer dry situation where N fertilizers could be substituted for some P fertilizers a differential policy designed to optimize production gave 2.1 Su/ha and 43 per cent margin increase compared to uniform application of typical rate of maintenance of P fertilizer only.

Kumar *et al.* (1999) described the use of GIS in soil productivity assessment of West Bengal soils. Soil of denuded hills, weathered pediments and valley fills were rated as extremely poor to poor in productivity whereas buried pediment soils had good productivity-spatial modeling and cartographic

capabilities of GIS software in generation of thematic maps were highlighted.

Acharya (2000) employed GIS to identify soil fertility status of Bari land based on information from survey data of representative sites and lab analysis report of soil samples collected from land at different sites giving focus on cropping systems, cultivation practices, terracing and soil which were the main factors governing the soil fertility status and maintenance. Crops grown in the cropping system were sufficient to maintain soil fertility at all sites but the cultivation practices were erosive. The size of terrace did not affect soil properties but slope and soil type had an effect on changes in soil properties related to fertility. High rainfall intensity, black soils, higher slope and existing cultivation practices were the main causes of degradation of soil fertility in the Bari land cropping systems. Bench terracing and field manuring practices were the factors protecting and maintaining soil fertility at all sites. Crop mulching, minimum tillage and less intercultural operation in field prevent soil movement and improve soil fertility for outwardly sloping areas without terracing.

Brown *et al.* (2000) evaluated GIS based approach to assess soil P degradation risks as influenced by site factors and human land use impacts. The status of P fertility in a Nepalese watershed was evaluated by stratifying the soil analysis by soil

type elevation, aspect and land use (irrigated and rainfed agriculture, rangeland and forest). Human impacts were shown to be significant and with GIS overlay technique produced the soil P status map based on land use and soil type. Twenty seven per cent of the area was deficient in P. soil nutrient budget displaying annual surveys of deficient condition for the common crops were combined with soil fertility map to derive a soil P degradation risk map. Low P conditions with high annual deficit posed the greatest degradation risk while adequate P status with high annual deficit was of more long-term concern. Forty seven per cent of the area was considered to be at low risk because of adequate conditions and minimum deficit of P.

Bai-Youli *et al.* (2001) developed ARC/INFO GIS soil nutrient management model based on grid sampling nutrient analysis and fertilizer recommendation. Using geostatistical method and information on soil spatial variability, the model is designed to manage soil nutrients and provide site specific management for areas of different soil fertility. In the Malan experimental areas of China, nutrient distribution map, classification map and nutrient maps were derived using this model. GIS technique was used to extend the K recommendation system into a systems for mapping spatially variable K requirement that accounts for crop demand and soil available K. Based on this yield of wheat were modeled. The site

of response depended on soil test values on plant available K. Wheat response to K was described by Mitscherlich equation.

Schreier *et al.* (1996) examined the nutrient dynamics for Bela watershed, Nepal using a range of GIS, budget modeling and field analysis techniques and reported that soil acidity, P availability and lack of base cations were the key soil fertility issues. Nutrient budget calculation revealed significant annual P deficit for maize rotation but only minimum deficit in rice rotation.

Maji *et al.* (1997) evaluated the soil fertility status by using the database generated through field surveys of Madhubani district at 1:50,000 scale. The spatial and non-spatial database were created in a GIS and thematic maps for physical and chemical properties were generated using 'reclassification technique' and statistical information provided.

Maji *et al.* (2000) developed a soil database of Madhya Pradesh in GIS at 1: 250,000 scale to upgrade the available digitized information of the state on 1: 500,000 scale and generated various thematic layers on physical and chemical properties by attribute-wise reclassification of soil maps. Area statistics were drawn for all thematic information for further spatial analysis and interpolation.

Das and Sarkar (1997) evaluated the dominant soils of summit and ridge side slope of hills and valleys for their

suitability to various crops *viz.*, maize, rice and mandarin suitability classes of these crops were evaluated taking into consideration of limitations of climate, topography, depth, texture, organic carbon and coarse fragments distribution. Indicated that maize can be grown in soils occurring on ridge and summit, very steep side slope more than 50 per cent, steep side slope (30-50%) and valley (<30%) while soils occurring in very steep slope is not suitable for rice cultivation and that soils occurring in valleys were highly suitable for mandarin due to favourable climate and soil conditions.

Thamgadge (1997) generated soil resource map for Madhya Pradesh from 851 mapping units at the level of association of soil family (on 1:250,000 scale) depicting soil depth, drainage, slope and erosion.

Srinivas *et al.* (1999) generated thematic map for Trissur district of Kerala using GIS. The input database include project information, soil map unit, pedon information, site characteristics, land use morphological characteristics and physical and chemical characteristics of soil.

Maji *et al.* (1999) employed GIS based on survey data (1:250,000 scale) for the North Eastern region. The attribute database consists information in site characteristics, morphological and chemical properties of soil of both dominant and sub-dominant soils in each map units.

2.2.1 Interpolations from point data

Interpolation is the procedure of predicting the value of attributes at uncomparing sites from measurements made at point locations within the same area or region. Interpolation is used to convert data from point observations to continuous fields so that the spatial patterns compared by these measurements can be compared with the spatial patterns of other spatial entries. Burrough and McDonnell (1998) described creation of continuous surfaces from point data. The methods of interpolation are of two main types: global method and local deterministic method. Local methods are preferred to the former. Of these the local deterministic method include Thiessen polygons and Pycnophylactic methods, linear and inverse distance weighting and thin plate splines. Out of these inverse distance interpolation is commonly used in GIS to create raster overlays from point data. Inverse distance interpolations commonly have a duck-egg pattern around solitary data points with values that differ greatly from their surrounding though this can be modified to a certain extent.

The flexible ruler used to achieve the best locally fitting smooth curves to sets of data points is called splines. Spline functions are mathematical equations of the flexible ruler (Burrough and McDonnell ,1998).

The advantage of splines are that as splines are piece-wise functions using few points at a time, the interpolating values can be equally calculated. Splines can retain small scale features. Both linear and surficial splines are aesthetically pleasing and quickly produce a clear overview of the data. The smoothness of splines means that mathematical derivations can easily be calculated for direct analysis of surface and topology.

Disadvantages of splines are that there are no direct estimates of the errors associated with spline interpolation though these may be obtained by a recursive technique known as 'jack - knifing' (Dubrule, 1984). The most critical disadvantage is that this plate splines provide a view of reality that is unrealistically smooth in some situations such as the estimation of attribute values for numerical models, this property could generate misleading results.

2.3 GIS AND LAND EVALUATION

Ranst *et al.* (1995) performed land evaluation with the aid of GIS linking the climate and soil information database to crop models simulating production potential. A combined application of a crop growth model and GIS was used to predict the maize production potential in the Northwest province of Cameroon at three hierarchically ordered production levels.

Tripathy *et al.* (1996) conducted a detailed evaluation of the indicators of desertification process in the semi-arid lands

of Karnataka using temporal satellite information along with the surface and statistical data with the aid of a GIS. The indicators were correlated to the surface information to establish the severity of desertification and factors helping the desertification process to continue. The results showed that the process was a natural phenomenon but was aggravated by human activity.

Milanova *et al.* (1995) performed scale dependent landscape mapping and studied the relationship among physical environment, land use and degree of landscape modification in the Aral Sea region and the Karakum desert areas prone to desertification in the Commonwealth of Independent states by employing GIS at global (1:15,000,000), regional (1:1,000,000) and local (1:300,000) scales. Large scale landscape assessment and mapping allowed the recognition of landscape changes under desertification process and assessment of the type and the intensity of these processes.

Wong *et al.* (2001) used Landsat thematic mapper (TM) data of a desert loess plateau in Shaanxi province, geometrically correlated and converted to an image map of 1:100,000. Vegetation types were automatically classified by the use of TM band ratios. Changes in desertification was also studied by comparing aerial photographs taken in 1960 and in 1987 and evaluated the results with the aid of GIS.

Slabo *et al.* (1998) compiled the information collected from bands on TM image. They used image classification and GIS technique for mapping the land degradation of two regions in Hungary at scale of 1:100,000. The Hortobagy test area located in the salinization-alkalinization region and the Matra area was vulnerable to water erosion. After image pre-processing, preliminary image analysis, stratification of the hortobagy area, application isodates clustering and temporal profile analysis of multitemporal image, five land cover classes associated with the salinity/alkalinity status of the grassland area were detailed.

Tekle and Redlund (2000) evaluated land cover changes in Kalu district by comparing two aerial photographs from 2 years 1958 and 1986 and its implications were related to land degradation using GIS. Two maps were produced in 1958 and 1986, which showed a decrease of 14.3 km² in Shrublands, riverine vegetation and forests and an increase in remaining open areas settlement, floodplains and water body, land cover changes observed were a result of clearing of vegetation for fuel wood, grazing lands and cultivation areas.

Petersen *et al.* (1997) overviewed the application of GIS in soil degradation assessment. It consists of essentiality of (1) the generation of thematic maps of attributes indicating the most affected or susceptible areas to soil degradation, (2) the parameterization of soil erosion or water quality model and 3)

development of interfaces between GIS and these models and spatial efficiency speed and accuracy.

Saenz *et al.* (1997) used GIS for identifying degraded soils associated with intensive deforestation in Costa Rica and depicted that only 44 per cent of the total of 89.25 km² were suitable for cultivation, forestry, agro-forestry and 7.64 per cent represent areas of high erodability.

Material and Methods

III. MATERIAL AND METHODS

The particulars relating to the geographical set up of the study area, physiography, collection and preparation of the soil samples and the analytical methods adopted in the present investigation are presented briefly in this chapter.

3.1 GEOGRAPHICAL SETTING OF THE STUDY AREA

Ghataprabha river is a tributary of Krishna which originates in the Western Ghats and on its Eastward path flows through the districts of Belgaum, Bijapur and Dharwad of Karnataka. The project has a storage dam located near Hidkal village of Hukkeri taluk of Belgaum district ($16^{\circ}9'N$ and $73^{\circ}34'E$) and upon its completion is expected to irrigate 7.81 lakh ha in the district of Belgaum and Bijapur with the left (GLBC) and right bank canal (GRBC) accounting for 4.0 lakh hectares and 3.84 lakh hectares, respectively.

An irrigated area of approximately 50,000 ha lying between GLBC main canal and Ghataprabha river in Belgaum district was selected for the study. The area presents a wide range in elevation ranging from 580 to 640 m above MSL and has varying geomorphic units. The area is represented by shallow, medium and some deep black soils. The crops grown are sugarcane, maize, turmeric, banana and vegetables.

The climate of the area is characterized by a mean annual rainfall of 347 mm most of which is received during July to

September. The major geological formation is Deccan basalt with a small portion of sandstone in the southwest corner of the study area.

The area under study is irrigated and intensively cultivated with commercial/high value crops. The production system is essentially high-input intensive with main crops being sugarcane, maize and wheat.

3.2 PHYSIOGRAPHIC UNIT DELINEATION

Map of India toposheet on 1:50,000 scale published by Survey of India for the study were obtained and joined. A tracing paper was placed on the toposheet and the physiographic delineation was done based on the contours and drainage network. The IRS 1D image data was also used to delineate the boundary of different unit. The outline of the study area was traced by keeping the IRS ID LISS III image of the study area of the same scale (Fig.1).

3.3 COLLECTION OF SOIL SAMPLES

Two hundred and forty two (242) surface (0-15 cm) soil samples were drawn from the area. The exact sample location was recorded using a GPS (global positioning system). The information on crops and crop rotation followed was also noted. The sampling locations is shown on IRS-ID LISS-III composite image of the area in the Fig.1.

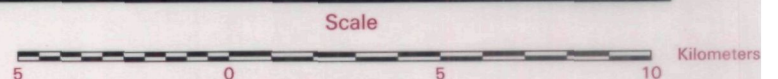
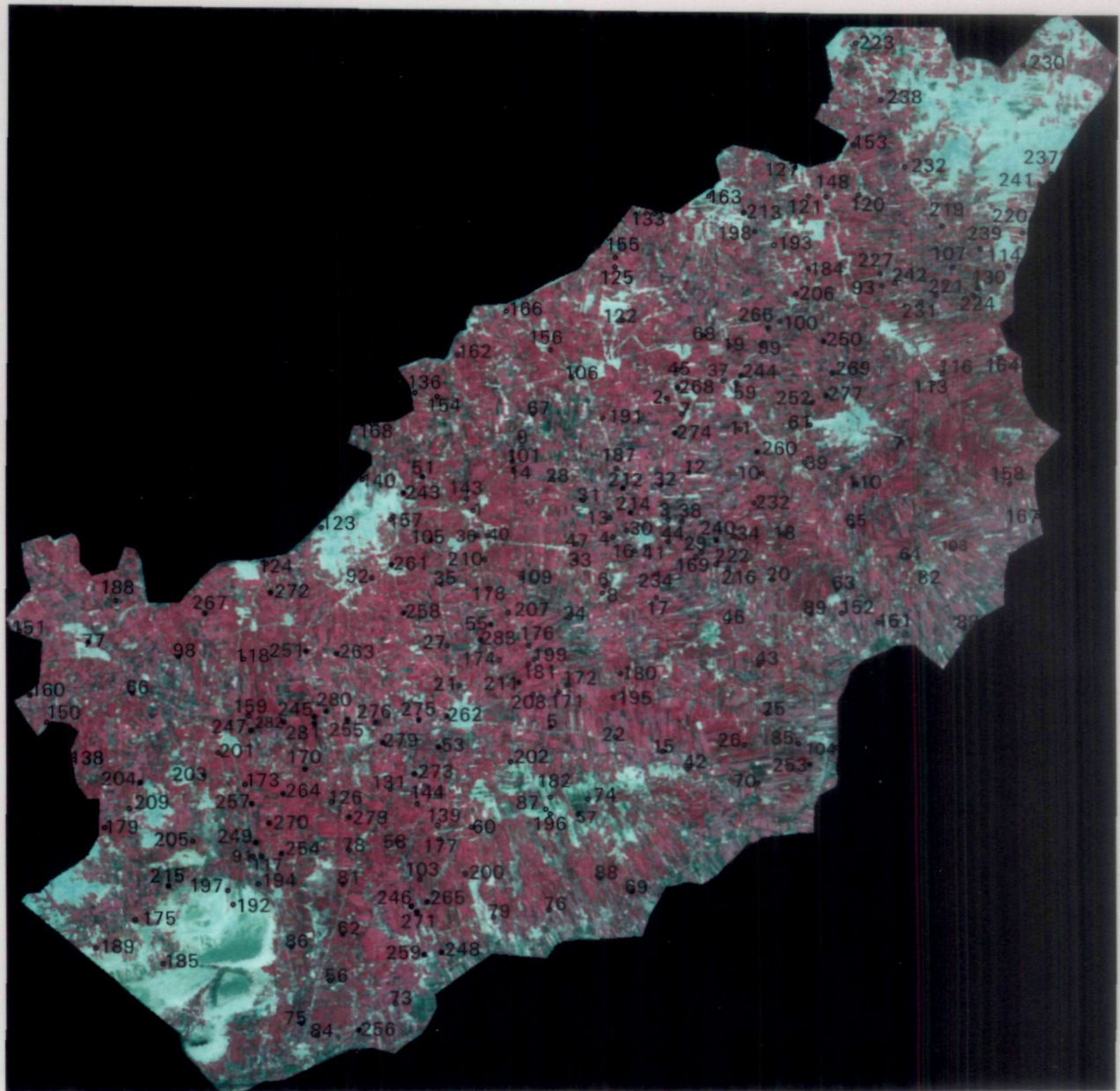


Fig.1: Map showing sampling locations in GLBC command area

Soil samples were first air-dried in shade, then powdered gently with a wooden mallet and sieved through 2 mm sieve and stored in clean polythene containers for further analysis.

3.5 ANALYSIS OF THE SAMPLES

The soils were analysed for the following parameters.

3.5.1 Soil reaction (pH)

The soil pH was measured in 1:2.5 soil water suspension using Systronics model 331 pH meter (Jackson, 1967).

3.5.2 Electrical conductivity

The EC (dS m^{-1}) was measured in the supernatant solution of 1:2.5 soil water suspension using Systronics model 334 conductivity bridge.

3.5.3 Organic carbon

Organic carbon was estimated by Walkley and Black wet oxidation method where organic matter in finely ground soil is oxidised by chromic acid by making use of heat of dilution of sulphuric acid for reaction (Jackson, 1967).

3.5.4 Calcium carbonate content

Calcium carbonate content was estimated by acid neutralization method using suitable indicators (Jackson, 1967).

3.5.5 Available nitrogen

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Available nitrogen was estimated by alkaline KMnO_4 method where the organic matter in soil is oxidised with hot alkaline KMnO_4 solution. The ammonia (NH_3) evolved during oxidation is distilled and trapped in boric acid mixed indicator solution. The amount of NH_3 trapped is estimated by titrating with standard acid (Subbaiah and Asija, 1956).

3.5.6 Available phosphorus

Available phosphorus was extracted with sodium bicarbonate (0.5 M) at pH 8.5 (Olsen's reagent) and the amount of P in the extract was estimated by chlorostannous reduced phosphomolybdate blue colour method using spectrophotometer at wavelength of 660 nm (Jackson, 1973).

3.5.7 Available potassium

Available K was extracted with neutral normal ammonium acetate and determined using flame photometer (Jackson, 1973).

3.5.8 Exchangeable calcium and magnesium

Calcium and magnesium in 1N ammonium acetate extract were determined as described by Jackson (1973) in which Ca and Mg were titrated against standard versanate solution (Ethylene diamine tetra acetate) using Eriochrome black-T indicator with NH_4Cl - NH_4OH as buffer.

Another aliquot was titrated in a similar way by using mureoxide indicator with NaOH as buffer in order to get values for calcium alone. Hence values for Mg can be obtained by subtracting value of Ca from the combine value of Ca and Mg.

3.5.9 Available sulphur

Sulphur in CaCl_2 (0.15%) extract was precipitated as barium sulphate and determined by measuring the intensity of turbidity formed using spectrophotometer at a wavelength of 420 nm (Jackson, 1973).

3.6 PREPARATION OF SOIL FERTILITY MAPS USING GIS

A dbf file consisting of data for X and Y coordinates in respect of sampling site location was created. A shape file (vector data) showing the outline of GLBC area was created in Arc View 3.1.

The dbf file was opened in the project window and in X-field X-coordinates was selected and in Y-field Y-coordinates was selected. The Z field was used for different nutrients. The GLBC shape file was also opened and from the "Surface menu" of Arc View spatial analyst "Interpolate grid option" was selected.

On the output "grid specification dialogue", output grid extend chosen was same as GLBC.shp and the interpolation method employed was spline. Then map was reclassified based on ratings of respective nutrients.

Experimental Results

IV. EXPERIMENTAL RESULTS

The results of the investigation carried out to assess the status of major nutrients *viz.*, primary nutrients N, P K and secondary nutrients (Ca, Mg, S) in the soils of Ghataprabha left bank are presented in this chapter.

The entire study area was physiographically delineated into four units namely,

1. Plateau
2. Hills
3. Gently undulating plains
4. Alluvial plain

Undulating plain occupies the highest area followed by plateau (Table 1). The spatial distribution of the units is shown in Fig 2.

4.1 SOIL PROPERTIES ON PLATEAU

The data pertaining to this physiographic delineation is presented below.

4.1.1 Soil reaction (pH) and Electrical conductivity (EC)

The data on pH and electrical conductivity is presented in Table 2. The pH of the soil samples on plateau ranged from 8.06 to 8.8 with a mean of 8.42 and standard deviation of 0.187.

Table 1. Area under different physiographic units of a portion of GLBC command area

Sl. No.	Physiographic unit	Area (ha)
1.	Plateau	14,438.9
2.	Hill	2,761.0
3.	Undulating plains	22,267.8
4.	Alluvial plains	6,562.2
	Total	46,029.9

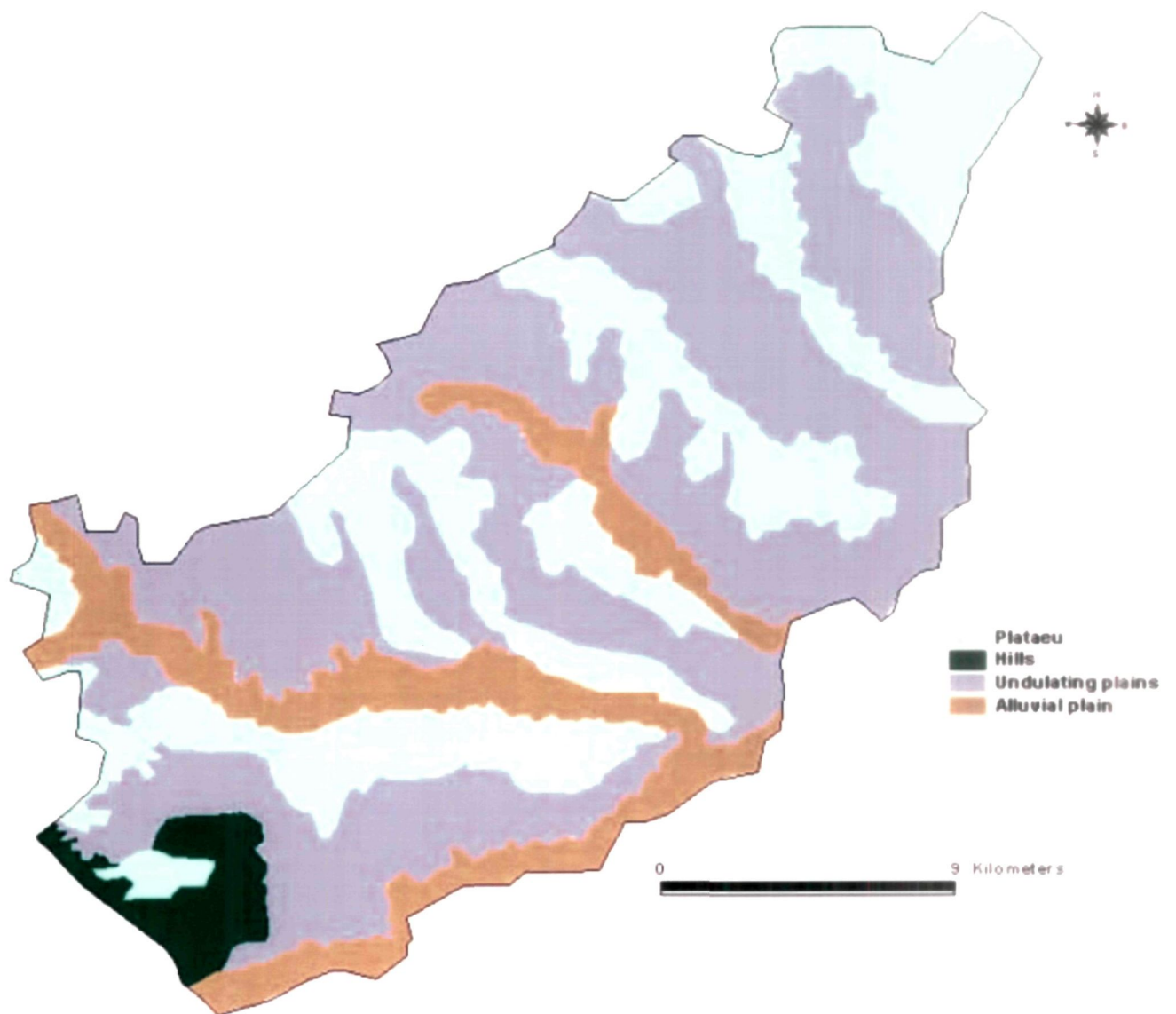


Fig. 2: Physiographic map of a portion of GLBC command area

Table 2: pH, EC, OC and CaCO₃ content in soils located on plateau

Sl. No.	Sample No.	pH	EC	OC	CaCO ₃
			dS m ⁻¹	%	%
1	1	8.06	0.27	0.87	5.33
2	4	8.59	0.27	0.49	6.25
3	6	8.37	0.22	0.74	6.20
4	8	8.44	0.40	0.86	7.63
5	15	8.39	0.20	0.80	7.93
6	17	8.21	0.19	0.99	5.78
7	21	8.74	0.29	0.80	7.60
8	22	8.42	0.43	0.47	6.40
9	30	8.41	0.32	0.48	8.40
10	33	8.42	0.56	0.79	8.83
11	36	8.23	0.12	0.76	7.15
12	40	8.32	0.38	0.48	8.88
13	43	8.42	0.41	0.76	7.13
14	51	8.42	0.40	0.82	11.55
15	57	8.56	0.33	0.44	7.43
16	58	8.77	0.39	0.58	7.23
17	60	8.43	0.41	1.14	8.73
18	70	8.30	0.61	0.60	8.53
19	74	8.63	0.30	0.79	6.68
20	78	8.33	0.22	0.75	7.80
21	81	8.25	0.50	0.72	6.90
22	87	8.70	0.19	0.68	9.38
23	92	8.12	0.11	1.28	6.73
24	105	8.45	0.39	0.86	9.05
25	113	8.35	0.23	0.82	8.33
26	114	8.13	0.65	1.04	8.53
27	116	8.64	0.36	0.65	8.83
28	121	8.55	0.54	0.86	7.47
29	123	8.12	0.29	0.74	8.97
30	126	8.36	0.19	0.89	8.43
31	127	8.19	0.32	0.98	7.59
32	131	8.39	0.62	0.97	8.13
33	133	8.62	0.28	0.82	7.35
34	139	8.26	0.35	0.75	8.63
35	140	8.32	0.24	0.68	6.43
36	143	8.41	0.49	0.87	7.43
37	144	8.36	0.44	0.91	7.00

38	148	8.65	0.52	0.59	6.70
39	151	8.20	0.45	0.86	7.20
40	163	8.12	0.26	1.33	7.13
41	171	8.72	0.55	0.72	6.35
42	172	8.45	0.36	0.52	7.35
43	173	8.68	0.61	0.49	6.25
44	176	8.31	0.38	0.59	7.33
45	178	8.50	0.59	0.64	6.35
46	179	8.44	0.62	0.55	7.38
47	181	8.23	0.41	0.69	7.10
48	182	8.57	0.32	0.62	5.75
49	185	8.80	0.56	0.71	5.25
50	188	8.78	0.41	0.84	6.55
51	189	8.33	0.26	0.77	5.73
52	195	8.20	0.51	0.69	7.23
53	196	8.66	0.45	0.71	5.13
54	199	8.22	0.35	0.80	7.23
55	203	8.53	0.35	0.66	7.13
56	204	8.60	0.55	0.73	7.33
57	207	8.36	0.31	0.82	7.98
58	209	8.40	0.61	0.77	8.33
59	210	8.56	0.24	0.84	7.43
60	220	8.35	0.24	0.70	9.20
61	223	8.25	0.29	0.71	7.53
62	230	8.41	0.45	0.75	7.13
63	237	8.65	0.25	0.65	6.13
64	241	8.20	0.46	0.86	7.93
65	243	8.21	0.36	0.69	7.95
67	257	8.62	0.13	0.72	7.15
67	258	8.58	0.17	0.84	7.55
68	261	8.62	0.20	0.77	7.33
69	264	8.19	0.19	0.99	7.60
70	273	8.36	0.22	0.80	9.23
71	278	8.22	0.31	0.93	10.50
Range		8.06-8.80	0.11-0.65	0.44-1.33	5.13-11.55
Mean		8.42	0.36	0.76	7.5
S.D.		0.187	0.140	0.170	1.17

The EC of the soils ranged from 0.11 to 0.65 dS m⁻¹ with a mean of 0.36 dS m⁻¹ and a standard deviation of 0.140.

4.1.2 Organic carbon (OC) and Calcium carbonate content

The organic carbon content of the soil ranged from 0.44 to 1.33 per cent with a mean of 0.76 per cent and a standard deviation of 0.170. About 85 per cent of samples in this physiography unit were medium in organic carbon, with 6 per cent in low and 9 per cent in high category (Table 2).

The calcium carbonate content of the soils studied ranged from 5.13 to 11.55 per cent and showed a mean of 7.5 per cent and standard deviation of 1.170 (Table2).

4.1.3 Available nitrogen, phosphorus and potassium

The results are presented in Table 3. The available nitrogen content of the soils ranged from 211.5 to 317.5 kg ha⁻¹ with a mean of 282.8 kg ha⁻¹ and a standard deviation of 21.0.

The values for available phosphorus content of soils studied under this category ranged from 12.4 to 38.0 kg ha⁻¹ with a mean of 23.3 kg ha⁻¹ and a standard deviation of 4.1.

The potassium content of the soil samples depicted in this category ranged from 201 to 689 kg ha⁻¹ with a mean of 422 kg ha⁻¹ and standard deviation of 111.

Of the total 71 samples on plateau area, 34 per cent analyzed low in nitrogen and 66 per cent were medium with none in high category. In respect of available phosphorus

Table 3: Available N, P, K content in soils located on plateau

Sl. No.	Sample No.	N	P	K
		kg ha ⁻¹	kg ha ⁻¹	kg ha ⁻¹
1	1	211.5	24.8	361
2	4	309.4	38.0	523
3	6	268.2	12.4	262
4	8	316.2	16.4	201
5	15	317.5	19.6	397
6	17	242.0	17.6	428
7	21	257.6	29.4	443
8	22	310.0	22.8	601
9	30	275.1	29.0	689
10	33	247.3	20.8	334
11	36	287.4	22.4	432
12	40	228.6	22.4	267
13	43	277.2	16.8	503
14	51	257.4	21.4	246
15	57	245.4	18.4	312
16	58	294.0	22.4	254
17	60	314.6	23.6	241
18	70	284.5	19.6	465
19	74	277.2	18.6	236
20	78	310.6	26.8	590
21	81	275.0	20.4	433
22	87	234.0	24.4	505
23	92	312.0	26.0	440
24	105	310.0	21.6	623
25	113	285.6	19.5	439
26	114	306.4	23.6	309
27	116	280.7	19.0	506
28	121	282.8	22.8	482
29	123	291.6	19.8	316
30	126	295.0	20.8	363
31	127	276.8	25.1	496
32	131	301.4	20.8	271
33	133	284.8	22.8	548
34	139	269.6	23.4	432
35	140	250.0	28.8	395
36	143	296.2	24.6	455
37	144	303.6	30.4	371

Contd...

38	148	267.8	23.6	542
39	151	281.0	23.6	632
40	163	312.0	20.6	284
41	171	287.4	27.6	479
42	172	293.8	22.4	389
43	173	302.4	18.0	375
44	176	289.6	28.0	391
45	178	286.2	23.8	280
46	179	269.4	27.6	400
47	181	270.8	19.4	369
48	182	273.2	23.8	430
49	185	298.8	30.8	523
50	188	289.0	24.8	493
51	189	290.8	22.4	598
52	195	296.6	18.4	547
53	196	282.0	26.4	415
54	199	287.6	19.4	562
55	203	282.0	20.4	514
56	204	289.0	26.0	438
57	207	297.0	22.8	426
58	209	277.0	26.8	338
59	210	283.0	20.2	426
60	220	297.0	22.6	516
61	223	286.0	24.8	351
62	230	298.0	24.0	298
63	237	273.0	27.2	476
64	241	281.0	24.0	438
65	243	282.0	29.2	417
67	257	293.0	23.8	314
67	258	261.0	21.0	320
68	261	289.0	24.0	330
69	264	283.0	28.0	560
70	273	280.0	28.4	603
71	278	299.0	20.4	316
Range		211.5-317.5	12.4-38.0	201-689
Mean		282.8	23.3	422
SD		21.0	4.1	111

63 per cent samples were high and 37 per cent medium with none in low category. Similarly, 89 per cent were high and 11 per cent medium in available potassium.

4.1.4 Exchangeable calcium, magnesium and available sulphur

The results are presented in Table 4. The exchangeable calcium content ranged from 18.0 to 37.1 cmol kg⁻¹ in the soils studied under this category. The mean recorded was 25.4 cmol kg⁻¹ and standard deviation was 4.70.

The exchangeable magnesium content of the soils categorized ranged from 4.2 to 20.2 cmol kg⁻¹ with a mean of 9.6 cmol kg⁻¹ and a standard deviation of 3.72.

The available sulphur content of the soils studied ranged from 18.1 to 50.9 kg ha⁻¹. The mean value observed was 27.8 kg ha⁻¹ and the standard deviation was 7.56. Expressed in percentage terms, majority of the samples were medium in available sulphur (85%), followed by high (9%) and a few (6%) were low.

4.2 SOIL PROPERTIES ON HILLS

The data pertaining to this physiographic division is presented below.

4.2.1 Soil reaction (pH) and electrical conductivity

The results pertaining to soil pH are presented in Table 5. The soils studied in relation to this aspect showed a range in

Table 4: Exchangeable Ca, Mg and available S content in soils located on plateau **39**

Sl. No.	Sample No.	Ca	Mg	S
		(cmol kg ⁻¹)	(cmol kg ⁻¹)	kg ha ⁻¹
1	1	23.6	6.8	23.2
2	4	27.4	6.8	43.3
3	6	33.0	11.5	31.8
4	8	24.0	12.2	32.1
5	15	30.4	18.0	30.5
6	17	22.4	20.2	23.9
7	21	23.6	8.5	32.6
8	22	26.2	6.8	39.2
9	30	25.1	17.3	50.9
10	33	26.6	9.1	47.2
11	36	22.4	7.4	35.1
12	40	37.1	5.4	31.3
13	43	22.6	17.4	33.8
14	51	31.0	6.8	47.5
15	57	19.8	10.7	48.7
16	58	26.6	12.0	32.0
17	60	26.4	6.2	24.4
18	70	29.8	11.9	19.8
19	74	20.1	11.5	41.3
20	78	32.0	6.8	20.7
21	81	19.6	10.2	35.9
22	87	31.3	6.1	26.1
23	92	21.2	13.6	23.5
24	105	30.4	6.2	33.1
25	113	27.6	12.2	23.2
26	114	28.2	7.4	18.2
27	116	33.6	6.5	30.4
28	121	22.4	14.4	26.9
29	123	32.8	4.4	24.4
30	126	30.0	10.6	18.1
31	127	21.2	12.6	27.8
32	131	23.6	8.2	20.4
33	133	25.6	5.4	25.5
34	139	27.2	12.6	20.7
35	140	18.0	12.6	22.9
36	143	22.4	12.8	30.8
37	144	28.0	4.6	27.4

Contd....

38	148	26.8	8.2	29.9
39	151	23.8	5.6	21.9
40	163	21.2	9.6	22.4
41	171	20.2	4.8	29.9
42	172	27.2	4.6	30.8
43	173	25.0	13.8	26.9
44	176	28.2	11.8	20.4
45	178	24.6	10.8	26.3
46	179	18.7	11.1	23.5
47	181	28.0	6.6	21.9
48	182	19.0	6.1	30.8
49	185	17.4	12.8	25.6
50	188	22.4	7.4	20.7
51	189	15.6	12.3	23.4
52	195	24.6	6.8	28.6
53	196	18.7	11.5	21.4
54	199	22.6	12.8	21.9
55	203	28.2	9.6	21.3
56	204	23.0	12.4	30.8
57	207	21.8	15.6	22.4
58	209	24.0	12.4	24.4
59	210	25.8	7.4	28.3
60	220	36.2	6.6	21.3
61	223	26.2	5.6	18.1
62	230	27.4	5.8	21.5
63	237	20.2	8.8	27.5
64	241	25.6	14.2	24.5
65	243	27.2	6.2	21.9
67	257	24.6	7.2	22.9
67	258	27.0	8.4	29.2
68	261	18.0	15.2	34.4
69	264	26.0	6.6	24.1
70	273	32.4	6.6	22.5
71	278	35.0	4.2	35.1
Range		18.0-37.1	4.2-20.2	18.1-50.9
Mean		25.4	9.6	27.8
SD		4.7	3.72	7.56

Table 5: pH, EC, OC and CaCO₃ in soils of hilly area

Sl.No.	Sample No.	pH	EC	OC	CaCO ₃
			dS m ⁻¹	%	%
1	7	8.16	0.23	0.78	6.78
2	10	8.38	0.12	1.04	6.98
3	11	8.42	0.17	0.98	7.25
4	12	8.41	0.25	0.49	8.67
5	18	8.36	0.31	0.60	8.83
6	32	8.25	0.16	0.93	7.58
7	37	8.18	0.61	0.80	7.65
8	39	8.56	0.39	0.45	7.93
9	45	8.14	0.63	0.56	7.18
10	64	8.96	0.44	1.18	8.80
11	65	8.33	0.30	0.49	8.93
12	68	8.47	0.32	0.73	7.60
13	82	8.38	0.32	0.54	7.35
14	108	8.44	0.52	0.54	6.45
15	110	8.76	0.32	1.10	6.00
16	122	8.76	0.33	0.69	9.13
17	192	8.72	0.39	0.98	6.40
18	194	8.59	0.42	1.12	5.93
19	197	8.48	0.22	0.64	6.23
20	323	8.50	0.27	0.89	7.97
21	247	8.28	0.28	0.70	6.93
22	260	8.47	0.63	0.79	10.30
23	268	8.40	0.34	0.73	8.13
Range		8.16-8.96	0.12-0.63	0.45-1.18	5.93-10.30
Mean		8.45	0.35	0.77	7.70
SD		0.204	0.143	0.221	1.20

pH from 8.16 to 8.56. The mean for these 23 samples were 8.45 and the standard deviation was 0.204.

The EC values for the soils ranged from 0.12 to 0.63 dS m⁻¹ with a mean of 0.35 dS m⁻¹ and a standard deviation of 0.143 (Table 5).

4.2.2 Organic carbon and Calcium carbonate content

The results of the organic carbon content of the soils under this division showed a wide range of 0.45 to 1.18 per cent (Table 5). The recorded mean was 0.77 per cent and the standard deviation was 0.221.

Of the several samples analysed 13 per cent samples were low in organic carbon content, 39 per cent medium and 48 per cent high in organic carbon content.

The calcium carbonate content of the soil samples ranged from 5.93 to 10.30 per cent with a mean of 7.70 per cent and standard deviation of 1.200 (Table 5).

4.2.3 Available nitrogen, phosphorus and potassium

The results pertaining to available nitrogen, phosphorus and potassium are presented in Table 6. The available nitrogen content in the soils of this division ranged from 248.6 to 317.8 kg ha⁻¹. The mean and standard deviation observed were 280.4 kg ha⁻¹ and 21.24, respectively.

Table 6: Available N, P, K content in soils of hilly area

Sl. No.	Sample No.	N	P	K
		kg ha ⁻¹	kg ha ⁻¹	kg ha ⁻¹
1	7	278.0	18.8	676
2	10	254.0	19.2	465
3	11	258.8	28.8	444
4	12	249.1	12.8	405
5	18	293.2	25.2	632
6	32	313.0	15.8	601
7	37	259.6	32.8	366
8	39	284.5	15.2	440
9	45	293.2	19.2	452
10	64	251.2	25.6	382
11	65	261.8	15.5	512
12	68	303.4	17.2	275
13	82	281.6	19.2	403
14	108	248.6	18.4	464
15	110	317.8	28.8	348
16	122	277.2	20.6	366
17	192	291.0	20.6	392
18	194	303.2	24.0	476
19	197	251.2	27.6	536
20	323	290.0	29.2	344
21	247	297.0	24.8	450
22	260	296.0	22.8	268
23	268	269.0	27.2	466
Range		248.6-317.8	12.8-32.8	268- 676
Mean		280.4	22.11	442
SD		21.24	5.39	102

The phosphorus content of the soils studied ranged from 12.8 to 32.8 kg ha⁻¹. The mean and standard deviation observed for these 23 samples were 22.11 kg ha⁻¹ and 5.39, respectively.

The potassium content of the soils categorized under this division ranged from 268 to 676 kg ha⁻¹. The mean and standard deviation were 442 kg and 102, respectively.

On physiographic unit, hills majority of the samples (56%) were low and 44 per cent medium in available nitrogen. The available phosphorus was equally distributed among medium (52%) and high (48%) categories. The available potassium was high in majority of the samples (91%) with only a few (9%) being medium in status.

4.2.4 Exchangeable calcium, magnesium and available sulphur

The exchangeable calcium content of the soils studied ranged between 16.6 and 32.0 cmol kg⁻¹ with a mean of 24.6 cmol kg⁻¹ and standard deviation of 4.99 (Table 7).

The magnesium content of the soils falling under this division ranged from 4.0 to 22.1 cmol kg⁻¹. The mean and standard deviation observed were 9.5 cmol kg⁻¹ and 3.63, respectively (Table 7).

The available sulphur content of the soils delineated showed a wide range of 17.5 to 53.2 kg ha⁻¹. The mean and

Table 7: Exchangeable Ca, Mg and available S content in soils of hilly area

Sl. No.	Sample No.	Ca	Mg	S
		(cmol kg ⁻¹)	(cmol kg ⁻¹)	kg ha ⁻¹
1	7	16.6	7.4	20.9
2	10	18.4	11.2	28.1
3	11	27.4	9.0	17.5
4	12	31.8	8.2	35.6
5	18	32.0	4.0	25.83
6	32	31.6	4.4	53.2
7	37	25.1	22.1	38.1
8	39	27.2	12.9	27.9
9	45	19.2	8.4	22.8
10	64	26.4	7.8	37.1
11	65	28.2	8.7	29.4
12	68	27.3	6.3	30.7
13	82	28.0	7.8	22.7
14	108	25.0	5.8	20.9
15	110	18.7	11.1	22.5
16	122	30.2	11.2	19.6
17	192	21.6	9.2	28.1
18	194	19.6	11.0	22.3
19	197	19.2	11.2	24.1
20	323	21.7	11.7	28.3
21	247	21.4	9.0	25.6
22	260	30.2	8.2	26.4
23	268	19.0	11.8	29.4
Range		16.6-32.0	4.0-22.1	17.5-53.2
Mean		24.6	9.5	37.4
SD		4.99	3.63	4.87

standard deviation observed for these 23 samples were 37.4 kg ha⁻¹ and 4.87, respectively (Table 7).

Maximum number of samples (87%) was rated as medium and 9 per cent as high with only 4 per cent as low in available sulphur content.

4.3 SOIL PROPERTIES ON GENTLY UNDULATING PLAINS

The data pertaining to pH, EC, organic carbon and calcium carbonate content of the 122 soil samples falling in this division are presented in Table 8.

4.3.1 Soil reaction (pH) and electrical conductivity

The results shown in Table 8 indicated that the 122 samples grouped in this class showed a range in pH from 8.02 to 8.86. The observed mean and standard deviation were 8.44 and 0.193, respectively.

The EC values of the soils studied under this category ranged from 0.11 to 1.4 dS m⁻¹ with a mean of 0.36 dS m⁻¹ and a standard deviation of 0.188. The maximum value for EC was observed in this division.

4.3.2 Organic carbon and calcium carbonate content

The organic carbon content of the soil samples delineated in this class ranged from 0.34 to 1.32 per cent with a mean of 0.8 per cent and a standard deviation of 0.184. The lowest value for organic carbon content was observed in this undulating plains (Table 8).

Table 8: pH, EC, OC and CaCO₃ content in soils located on gently undulating plains

Sl. No.	Sample No.	pH	EC	OC	CaCO ₃
			dS m ⁻¹	%	%
1	2	8.59	0.31	0.42	6.11
2	3	8.42	0.30	0.34	6.53
3	13	8.23	0.15	0.83	9.30
4	14	8.45	0.25	1.08	7.06
5	19	8.45	0.25	0.74	7.40
6	20	8.72	0.51	0.86	8.03
7	24	8.42	0.13	1.13	9.23
8	25	8.34	0.20	0.72	7.33
9	26	8.54	0.29	0.36	8.73
10	27	8.69	0.33	1.03	8.17
11	28	8.64	0.13	0.48	7.06
12	29	8.14	0.11	0.77	8.33
13	31	8.77	0.18	0.74	8.43
14	34	8.41	0.25	0.39	5.17
15	35	8.62	0.46	0.44	7.58
16	38	8.45	0.25	0.59	10.45
17	47	8.60	0.35	1.09	7.07
18	55	8.41	0.28	0.69	7.93
19	56	8.45	0.25	0.74	8.63
20	58	8.77	0.39	0.58	7.23
21	59	8.40	0.22	0.77	10.86
22	61	8.56	0.96	0.96	8.42
23	62	8.18	0.23	0.95	6.70
24	63	8.23	0.36	1.12	9.20
25	67	8.36	0.24	1.12	7.38
26	69	8.19	0.26	0.57	9.32
27	71	8.41	0.35	0.95	9.98
28	73	8.26	0.54	1.09	7.17
29	75	8.27	0.25	1.12	7.98
30	76	8.49	0.36	0.93	8.68
31	79	8.86	0.61	0.84	7.13
32	83	8.55	0.11	0.87	7.70
33	85	8.61	0.26	1.20	7.95
34	86	8.80	0.20	0.47	8.75
35	88	8.22	0.65	0.72	6.80
36	89	8.45	0.22	0.62	7.13

Contd....

37	91	8.39	0.31	1.32	7.38
38	93	8.26	1.40	0.45	6.98
39	98	8.72	0.18	0.82	7.85
40	99	8.26	0.57	0.90	7.10
41	100	8.31	0.32	0.84	7.25
42	101	8.30	0.25	0.97	6.97
43	103	8.19	0.43	0.56	8.93
44	104	8.23	0.26	1.13	7.45
45	106	8.61	0.48	0.89	6.23
46	107	8.36	0.87	1.13	8.10
47	109	8.83	0.24	0.49	6.73
48	117	8.59	0.47	0.73	6.73
49	118	8.81	0.39	0.64	7.10
50	120	8.27	0.40	0.98	6.13
51	125	8.15	0.27	0.78	7.47
52	124	8.30	0.20	1.00	9.23
53	130	8.44	0.36	0.79	7.35
54	136	8.53	0.27	0.94	7.57
55	138	8.76	0.54	0.80	8.97
56	152	8.36	0.50	0.67	6.95
57	153	8.71	0.45	1.00	6.50
58	154	8.22	0.20	0.86	5.95
59	155	8.35	0.42	0.80	6.68
60	156	8.44	0.31	0.78	6.45
61	158	8.50	0.34	0.50	7.43
62	159	8.81	0.60	0.69	7.15
63	161	8.45	0.59	0.62	7.25
64	162	8.28	0.35	0.48	7.73
65	164	8.36	0.51	0.91	8.23
67	165	8.42	0.30	0.65	6.97
67	167	8.31	0.35	0.79	7.75
68	166	8.71	0.40	0.71	7.40
69	168	8.29	0.43	0.81	6.45
70	174	8.43	0.54	0.72	6.35
71	175	8.77	0.40	0.78	7.95
72	180	8.68	0.56	0.92	7.95
73	184	8.63	0.33	0.84	6.40
74	188	8.78	0.41	0.84	6.55
75	191	8.41	0.50	0.74	7.38
76	193	8.30	0.27	0.81	6.73

Contd..

77	198	8.54	0.29	0.58	6.97
78	200	8.60	0.56	0.71	7.00
79	205	8.30	0.43	0.90	6.98
80	206	8.42	0.29	0.81	7.37
81	208	8.78	0.29	0.89	7.06
82	211	8.28	0.11	0.92	6.93
83	215	8.48	0.53	0.91	8.40
84	216	8.72	0.34	0.70	8.13
85	219	8.43	0.35	0.85	8.13
86	221	8.23	0.46	0.72	6.97
87	222	8.47	0.13	0.71	7.23
88	224	8.30	0.34	0.86	8.06
89	231	8.30	0.56	1.07	8.58
90	232	8.50	0.27	0.89	7.97
91	233	8.32	0.39	0.95	6.33
92	238	8.24	0.22	0.92	6.90
93	239	8.33	0.64	0.83	7.13
94	240	8.72	0.28	0.77	6.38
95	242	8.43	0.55	0.80	8.10
96	244	8.34	0.42	0.92	6.43
97	245	8.15	0.18	0.85	7.15
98	246	8.46	0.23	0.65	7.07
99	248	8.54	0.47	0.73	8.33
100	249	8.26	0.39	0.56	7.58
101	250	8.63	0.12	0.97	7.75
102	251	8.51	0.36	0.86	6.95
103	252	8.49	0.24	0.84	7.05
104	253	8.02	0.52	0.93	9.30
105	254	8.19	0.34	0.83	9.88
106	255	8.35	0.22	0.64	8.95
107	258	8.58	0.17	0.84	7.55
108	262	8.38	0.14	0.69	8.15
109	263	8.24	0.32	0.55	7.98
110	265	8.21	0.25	0.67	6.43
111	266	8.11	0.14	0.86	10.58
112	267	8.34	0.23	0.85	9.06
113	269	8.17	0.50	0.80	7.98
114	270	8.50	0.28	0.76	8.13
115	271	8.32	0.45	0.83	8.53
116	272	8.45	0.36	0.82	7.58

Contd...

117	274	8.21	0.19	0.82	8.58
118	277	8.36	0.26	0.82	8.97
119	280	8.81	0.94	0.81	8.06
120	281	8.45	0.11	0.84	6.33
121	282	8.18	0.48	0.66	8.98
122	283	8.13	0.62	0.84	7.23
Range		8.02-8.86	0.11-1.40	0.34-1.32	5.17-10.86
Mean		8.44	0.36	0.80	7.60
SD		0.193	0.188	0.184	0.180

Majority of the samples in this physiographic unit were high (66%) in organic carbon followed by medium (27%) with only 7 per cent as low.

The calcium carbonate content ranged from 5.17 to 10.86 per cent in the soils studied under this delineation. The observed mean and standard deviation were 7.60 per cent and 0.180, respectively.

4.3.3 Available nitrogen, phosphorus and potassium

The data pertaining to available nitrogen, phosphorus and potassium content of the 122 soil samples falling in gently undulating plains are presented in Table 9.

The soils studied under this category showed a range in available nitrogen content from 224.0 to 321.6 kg ha⁻¹ with a mean of 280.5 kg ha⁻¹ and standard deviation of 59.5.

The content of phosphorus in the soils studied under this deviation ranged from 12.0 to 35.1 kg ha⁻¹. The mean and standard deviation observed were 24.3 kg ha⁻¹ and 4.43, respectively.

The available potassium content of soil samples studied in this group ranged from 218 to 675 kg ha⁻¹ with a mean value of 413 kg ha⁻¹ and standard deviation of 107.

On this physiographic unit, majority of the samples (61%) were medium and 39 per cent low in available nitrogen. The available phosphorus was also high in more than two-third

Table 9: Available N, P, K content in soils located on gently undulating plains

Sl. No.	Sample No.	N	P	K
		kg ha ⁻¹	kg ha ⁻¹	kg ha ⁻¹
1	2	287.2	12.0	586
2	3	237.0	28.8	243
3	13	261.0	26.6	355
4	14	224.0	26.2	404
5	19	291.8	23.8	227
6	20	233.4	16.8	459
7	24	282.3	13.2	218
8	25	304.3	19.2	383
9	26	272.2	17.6	485
10	27	313.6	23.6	635
11	28	297.5	18.0	516
12	29	249.2	19.4	207
13	31	309.6	27.6	485
14	34	243.5	34.2	542
15	35	229.4	26.4	352
16	38	296.0	14.6	655
17	47	291.8	18.6	320
18	55	295.4	17.2	229
19	56	233.8	30.0	262
20	58	294.0	22.4	254
21	59	286.8	21.2	294
22	61	299.7	20.8	390
23	62	278.8	26.2	327
24	63	308.8	19.2	311
25	67	275.8	34.2	401
26	69	273.0	25.6	336
27	71	289.8	27.2	337
28	73	285.4	20.2	302
29	75	257.6	28.4	516
30	76	273.0	35.1	429
31	79	294.2	19.6	354
32	83	298.2	21.6	561
33	85	269.6	19.6	675
34	86	310.4	29.2	338
35	88	293.2	20.2	239
36	89	270.8	23.0	218
37	91	293.6	18.8	420

Contd.

38	93	265.2	21.6	568
39	98	260.5	25.0	525
40	99	291.8	20.8	367
41	100	287.4	18.0	451
42	101	249.8	24.8	396
43	103	254.0	29.7	543
44	104	321.6	17.7	653
45	106	249.2	25.1	393
46	107	275.0	24.8	549
47	109	266.0	21.2	323
48	117	282.6	21.6	412
49	118	249.6	22.4	353
50	120	279.8	32.2	295
51	125	269.6	26.0	440
52	124	316.5	28.4	230
53	130	304.8	30.2	633
54	136	277.4	30.8	518
55	138	216.0	20.6	390
56	152	267.4	21.8	452
57	153	304.4	26.4	548
58	154	293.2	31.0	492
59	155	279.0	18.8	318
60	156	263.8	26.2	932
61	158	260.0	31.4	373
62	159	297.2	30.0	523
63	161	283.4	23.6	425
64	162	265.2	28.4	375
65	164	294.8	19.8	566
67	165	273.6	23.2	323
67	167	291.8	25.2	519
68	166	280.4	26.8	480
69	168	287.4	28.4	436
70	174	298.0	20.6	391
71	175	282.4	24.4	433
72	180	297.4	24.0	386
73	184	295.0	24.0	332
74	188	289.0	24.8	493
75	191	279.2	23.2	320
76	193	293.6	26.8	256
77	198	280.8	21.8	430

Contd....

78	200	284.0	20.2	391
79	205	290	24.8	380
80	206	291.0	23.2	402
81	208	307.0	29.4	430
82	211	273.0	29.6	440
83	215	283.0	27.6	403
84	216	301.0	23.2	324
85	219	284.0	24.2	392
86	221	276.0	23.8	295
87	222	289.0	27.4	438
88	224	291.0	21.0	439
89	231	300.0	25.8	518
90	232	290.0	29.2	344
91	233	295.0	22.4	486
92	238	289.0	23.8	317
93	239	270.0	22.4	429
94	240	278.0	28.2	513
95	242	286.0	23.6	284
96	244	291.0	25.6	394
97	245	298.0	22.0	452
98	246	285.0	29.2	584
99	248	265.0	21.6	428
100	249	273.0	30.2	624
101	250	293.0	21.4	362
102	251	286.0	24.8	395
103	252	285.0	29.0	402
104	253	290.0	20.2	937
105	254	293.0	28.0	413
106	255	274.0	27.6	590
107	258	261.0	21.0	320
108	262	278.0	25.8	343
109	263	265.0	27.0	561
110	265	267.0	20.8	414
111	266	294.0	19.4	325
112	267	283.0	24.6	534
113	269	273.0	26.0	348
114	270	297.0	28.2	410
115	271	287.0	23.8	394
116	272	291.0	22.4	546

Contd..

117	274	289.0	31.0	412
118	277	297.0	18.6	263
119	280	294.0	29.8	342
120	281	286.0	27.0	648
121	282	271.0	30.6	502
122	283	274.0	24.8	349
Range		224.0 -321.6	12.0 -35.1	218-675
Mean		280.5	24.3	413
SD		59.5	4.43	107

samples (69%) and another one-third (31%) had medium levels. The available potassium was high in majority of the samples (90%) with only a few (10%) being of medium in status.

4.3.4 Exchangeable calcium, magnesium and available sulphur

The data pertaining to exchangeable calcium and magnesium and available sulphur content of the 122 soil samples falling in gently undulating plains are presented in Table 10.

The exchangeable calcium content of the soils under this delineation ranged from 10.4 to 37.4 cmol kg⁻¹ with a mean value of 25.4 cmol kg⁻¹ and a standard deviation of 4.60.

The magnesium content of the soils falling under this category ranged from 2.2 to 21.4 cmol kg⁻¹. The mean and standard deviation observed were 10.11 cmol kg⁻¹ and 3.57, respectively.

The sulphur content ranged from 18.1 to 52.9 kg ha⁻¹ in the soils studied under this category. The mean and standard deviation observed were 27.21 kg ha⁻¹ and 7.50, respectively.

Maximum samples were medium in available sulphur (84%) with about 8 per cent samples each in low and high category.

Table 10: Exchangeable Ca, Mg and available S content in soils located on gently undulating plains

Sl. No.	Sample No.	Ca	Mg	S
		(cmol kg ⁻¹)	(cmol kg ⁻¹)	kg ha ⁻¹
1	2	27.2	6.4	37.8
2	3	33.7	8.7	52.9
3	13	35.0	11.0	26.3
4	14	28.0	4.6	38.5
5	19	25.4	3.8	41.3
6	20	24.6	7.2	29.5
7	24	26.2	16.2	31.8
8	25	19.6	11.0	20.0
9	26	23.6	10.2	45.2
10	27	28.4	10.6	19.7
11	28	15.2	10.4	25.6
12	29	22.4	9.4	32.3
13	31	24.6	7.4	49.8
14	34	10.4	12.0	38.4
15	35	21.7	11.7	23.9
16	38	39.0	6.0	18.2
17	47	22.6	15.8	41.3
18	55	20.0	14.8	36.4
19	56	25.2	15.0	25.9
20	58	26.6	12.0	32.0
21	59	37.4	6.4	29.4
22	61	25.0	17.2	37.5
23	62	20.2	13.4	34.4
24	63	30.2	7.2	40.6
25	67	27.6	12.0	44.0
26	69	32.5	13.3	23.6
27	71	33.8	13.2	27.3
28	73	22.5	14.5	32.0
29	75	23.6	12.4	27.3
30	76	32.4	9.4	24.4
31	79	27.6	13.2	43.1
32	83	25.6	6.8	38.4
33	85	25.4	21.4	33.2
34	86	32.0	9.6	42.4
35	88	21.0	15.0	29.4
36	89	26.5	5.9	26.9
37	91	25.2	21.0	34.4

Contd...

38	93	22.8	8.4	31.4
39	98	28.6	14.4	20.1
40	99	24.7	8.7	30.7
41	100	28.4	12.0	27.7
42	101	21.0	15.8	23.6
43	103	32.0	5.0	51.1
44	104	28.4	7.2	30.6
45	106	18.0	16.0	20.8
46	107	20.2	7.4	18.7
47	109	28.4	6.2	21.8
48	117	19.0	8.6	19.5
49	118	24.6	7.4	24.9
50	120	18.8	11.8	20.1
51	125	25.6	12.4	22.7
52	124	35.0	8.4	20.9
53	130	21.7	11.7	26.9
54	136	26.8	10.8	18.1
55	138	30.8	7.8	21.9
56	152	24.0	12.0	16.6
57	153	21.4	12.6	20.9
58	154	17.6	13.2	21.3
59	155	26.0	7.4	19.4
60	156	21.0	11.0	17.5
61	158	25.8	2.2	23.9
62	159	24.0	15.6	21.7
63	161	29.0	9.4	23.1
64	162	25.8	10.4	20.7
65	164	28.0	6.6	26.3
67	165	18.4	11.2	20.9
67	167	27.0	6.4	25.6
68	166	27.8	3.6	23.4
69	168	21.8	12.2	24.4
70	174	24.4	11.8	28.4
71	175	30.8	5.6	19.9
72	180	20.4	7.2	20.4
73	184	21.8	11.4	20.7
74	188	22.4	7.4	20.7
75	191	27.4	6.4	21.3
76	193	25.4	6.6	25.6

77	198	25.0	12.6	22.9
78	200	25.4	5.4	27.4
79	205	24.6	7.8	24.4
80	206	25.2	13.6	23.1
81	208	19.6	11.2	27.1
82	211	21.4	8.4	23.8
83	215	24.6	5.8	25.8
84	216	21.2	7.4	20.6
85	219	27.4	8.8	28.8
86	221	23.6	5.8	20.1
87	222	27.2	11.2	23.9
88	224	28.2	6.8	20.8
89	231	22.8	13.2	26.3
90	232	21.7	11.7	28.3
91	233	20.2	12.6	20.6
92	238	23.2	11.4	23.2
93	239	24.8	10.2	30.8
94	240	21.4	16.0	22.9
95	242	20.6	11.0	25.1
96	244	18.4	9.6	24.3
97	245	24.6	7.6	23.7
98	246	28.2	11.2	26.3
99	248	29.4	8.4	25.8
100	249	26.2	7.8	20.6
101	250	27.6	5.0	28.5
102	251	19.8	10.4	23.3
103	252	24.2	11.8	22.9
104	253	30.2	7.2	27.5
105	254	32.0	11.2	21.3
106	255	27.2	6.4	32.3
107	258	27.0	7.0	29.2
108	262	24.6	8.4	32.8
109	263	21.8	12.2	39.3
110	265	20.2	5.6	26.4
111	266	35.0	6.6	20.2
112	267	24.2	14.2	22.1
113	269	26.4	16.8	21.6
114	270	24.8	13.6	25.6
115	271	29.0	8.2	28.4

116	272	29.8	7.0	24.4
117	274	28.6	14.6	30.4
118	277	28.2	12.0	19.1
119	280	23.8	9.4	20.7
120	281	23.0	11.0	21.8
121	282	33.6	7.2	29.4
122	283	29.0	6.6	30.6
Range		10.4-37.4	2.2-21.4	18.1-52.9
Mean		25.4	10.1	27.2
SD		4.60	3.57	7.50

The data pertaining to 26 soil samples falling in this division are presented in Table 11.

4.4.1 Soil reaction (pH) and electrical conductivity

The values for pH of the soils studied ranged from 8.10 to 8.86 with a mean of 8.4 and a standard deviation of 0.220.

The EC values of the samples falling under this delineation ranged from 0.13 to 0.96 dS m⁻¹ with a mean of 0.37 dS m⁻¹ and standard deviation of 0.189.

4.4.2 Organic carbon and calcium carbonate content

The organic carbon content of the soils studied in this class ranged from 0.49 to 1.13 per cent with a mean and standard deviation of 0.80 per cent and 0.161, respectively (Table 11).

The organic carbon content of 57 per cent samples was high and of 39 per cent was medium in status with only 4 per cent samples being in low category.

The calcium carbonate content of the soils studied ranged from 5.23 to 9.75 per cent. The mean was 7.37 per cent and standard deviation was 1.06 (Table 11).

4.4.3 Available nitrogen, phosphorus and potassium

The results pertaining to available nitrogen, phosphorus and potassium content of the soil falling under this division have been presented in Table 12. The available nitrogen content

Table 11: pH, EC, OC and CaCO₃ contents in the soils of alluvial plain

Sl. No.	Sample No.	pH	EC	OC	CaCO ₃
			dS m ⁻¹	%	%
1	5	8.80	0.61	0.68	5.23
2	9	8.14	0.13	0.89	6.85
3	16	8.43	0.18	0.61	6.83
4	41	8.19	0.23	1.00	5.95
5	42	8.62	0.40	0.67	6.67
6	44	8.51	0.20	0.82	6.95
7	46	8.42	0.26	1.11	6.70
8	53	8.21	0.20	1.13	7.95
9	66	8.51	0.16	0.69	9.75
10	77	8.21	0.45	0.56	7.55
11	79	8.86	0.61	0.84	7.13
12	84	8.74	0.96	0.62	8.35
13	150	8.24	0.37	0.99	7.05
14	160	8.62	0.13	0.49	6.67
15	169	8.30	0.23	0.74	7.06
16	170	8.38	0.47	0.78	6.70
17	201	8.18	0.51	0.74	7.37
18	202	8.76	0.26	0.68	7.97
19	212	8.37	0.43	0.79	7.10
20	214	8.39	0.46	1.04	9.37
21	234	8.23	0.40	0.76	8.53
22	256	8.27	0.40	0.74	7.23
23	259	8.23	0.29	0.80	6.35
24	275	8.10	0.60	0.83	7.63
25	276	8.28	0.38	0.89	7.13
26	279	8.43	0.27	0.82	9.58
Range		8.10 -8.86	0.13-0.96	0.49 -1.13	5.23-9.75
Mean		8.40	0.37	0.80	7.37
SD		0.22	0.189	0.161	1.60

Table 12: Available N, P, K content in the soils of alluvial plain

Sl. No.	Sample No.	N	P	K
		kg ha ⁻¹	kg ha ⁻¹	kg ha ⁻¹
1	5	313.0	26.6	468
2	9	298.3	21.6	439
3	16	233.8	24.4	626
4	41	307.2	28.2	418
5	42	247.0	19.6	534
6	44	309.6	12.8	218
7	46	259.6	14.4	503
8	53	282.0	23.4	524
9	66	301.7	28.4	472
10	77	260.4	23.2	273
11	79	294.2	19.6	354
12	84	245.0	18.0	452
13	150	293.8	24.4	389
14	160	270.8	19.8	567
15	169	263.8	32.0	454
16	170	282.0	29.4	399
17	201	278.0	26.8	498
18	202	271.0	23.4	375
19	212	294.0	22.0	318
20	214	305.0	24.0	465
21	234	289.0	20.8	292
22	256	291.0	26.2	291
23	259	273.0	24.6	396
24	275	287.0	29.2	468
25	276	278.0	28.2	501
26	279	302.0	21.0	215
Range		233.8-313.0	12.8-32.0	215-626
Mean		281.9	23.5	420
SD		21.1	4.60	105

of the soils which were grouped in this class, ranged from 233.8 to 313.0 kg ha⁻¹ with a mean and standard deviation of 281.9 kg ha⁻¹ and 21.1, respectively.

The Phosphorus content ranged from 12.8 to 32.0 kg ha⁻¹ in the soils studied under this category. The mean and standard deviation were 23.51 kg ha⁻¹ and 4.60, respectively.

The potassium content of the soil delineated in this class ranged from 215 to 626 kg ha⁻¹ with a mean of 420 kg ha⁻¹ and standard deviation of 105.

The available nitrogen in majority of the samples (58%) was of medium status with 42 per cent samples in low category in this physiographic position. As in the undulating plains two-third samples (65%) were high and one-third samples (35%) were medium in available phosphorus. Available potassium was high in maximum number of samples (88%) with 12 per cent being of medium status.

4.4.4 Exchangeable calcium, magnesium and available sulphur

The results pertaining to exchangeable calcium, magnesium and available sulphur content of the soil falling under this division have been presented in Table 13.

The exchangeable calcium content of the soils ranged from 15.4 to 34.6 cmol kg⁻¹. The mean and standard deviation observed were 23.67 cmol kg⁻¹ and 5.09, respectively.

Table 13: Exchangeable Ca, Mg and available S content in the soils of alluvial plain

Sl. No.	Sample No.	Ca	Mg	S
		(cmol kg ⁻¹)	(cmol kg ⁻¹)	kg ha ⁻¹
1	5	15.4	11.0	22.5
2	9	21.6	9.2	41.4
3	16	28.0	4.0	41.2
4	41	18.6	6.0	21.2
5	42	20.2	16.8	29.2
6	44	21.4	12.6	20.3
7	46	18.7	11.1	49.3
8	53	25.7	13.6	23.9
9	66	34.6	3.2	33.1
10	77	28.0	11.2	36.8
11	79	27.6	13.2	43.1
12	84	29.0	6.6	45.6
13	150	18.4	13.0	28.7
14	160	26.4	8.2	20.8
15	169	19.2	9.6	28.1
16	170	22.8	7.8	22.5
17	201	21.2	12.2	31.1
18	202	26.0	6.6	22.4
19	212	20.8	10.6	20.1
20	214	30.2	7.6	21.9
21	234	28.8	10.8	25.9
22	256	20.4	9.8	19.2
23	259	19.2	7.8	23.9
24	275	17.4	11.2	21.7
25	276	22.6	16.0	29.4
26	279	33.0	5.0	23.6
Range		15.4-34.6	3.2-16.8	19.8-49.3
Mean		23.7	9.8	28.7
SD		5.09	3.45	8.88

The range of magnesium content in the soils studied under this delineation was from 3.2 to 16.8 cmol kg⁻¹. The mean and standard deviation observed from these 26 soil samples were 9.8 cmol kg⁻¹ and 3.45, respectively.

The available sulphur content of the soils ranged from 19.8 to 49.3 kg ha⁻¹ with a mean of 28.7 kg ha⁻¹ and standard deviation of 8.88.

In percentage terms as in other physiographic unit, majority of the samples were of medium status (77%) followed by high (19%) and the least number of samples as low (4%). The proportion of samples analyzed as high in available sulphur is relatively more in this unit than in any other unit.

4.5 Overall soil fertility status of the study area

The overall mean, standard deviation and range with respect to different parameters of the 242 samples is presented in Table 14. The pH of the soils of the entire study area ranged from 2.02 to 8.96 with a mean of 8.43 and standard deviation of 0.19. The EC values ranged from 0.11 to 1.4 dS m⁻¹. The mean and standard deviation for EC were 0.36 dS m⁻¹ and 0.17, respectively.

The organic carbon content of the soils ranged from 0.34 to 1.33 per cent with a mean of 0.79 per cent and standard deviation of 0.18. The calcium carbonate content ranged from 5.13 to 11.55 per cent. The mean and standard deviation of

Table: 14 Overall mean, standard deviation and range of soil properties and nutrient status in samples from GLBC area

Property	Mean	SD	Range
pH	8.43	0.19	8.02- 8.96
EC	0.36	0.17	0.11- 1.40
OC	0.79	0.18	0.34- 1.33
CaCO ₃	7.70	1.20	5.13- 11.55
N	283.6	41.96	211.5- 321.6
P	223.9	4.47	12.0- 38.0
K	426.0	107.71	201.0- 697.0
Ca	25.3	4.84	10.4- 39.0
Mg	9.9	3.54	2.2- 22.1
S	28.1	15.86	17.5- 53.3

calcium carbonate content were 7.70 per cent and 1.20, respectively.

The available nitrogen status of the soils ranged from 211.5 to 321.6 kg ha⁻¹ with a mean of 283.6 kg ha⁻¹ and standard deviation of 41.96. The available phosphorus status of soils ranged from 12.0 to 38.0 kg ha⁻¹ with a mean of 23.9 kg ha⁻¹ and standard deviation of 4.47. The range of available potassium were from 201.0 to 697.0 kg ha⁻¹. The mean and standard deviation were 426 kg ha⁻¹ and 107.71, respectively.

The exchangeable calcium content of soils ranged from 10.4 to 39.0 cmol kg⁻¹ with a mean of 25.3 cmol kg⁻¹ and 4.84 as standard deviation. The range, mean and standard deviation for exchangeable magnesium content of soils were 2.2 to 22.1 cmol kg⁻¹, 9.9 cmol kg⁻¹ and 3.54, respectively. The available sulphur content ranged from 17.5 to 53.3 kg ha⁻¹ with a mean of 28.1 kg ha⁻¹ and standard deviation of 15.86.

Discussion

V. DISCUSSION

The results of the investigation are discussed in this chapter. A portion of Ghataprabha Left Bank Canal (GLBC) area (46,029.9 ha) selected for the study has been divided into four physiographic divisions namely, the plateau (4,438.9 ha), hills (2,761 ha), undulating plains (22,267.8 ha) and alluvial plains (6,562.2 ha). The soil properties studied in each of the divisions along with the data on soil properties in relation to cropping pattern is discussed.

5.1 GENERAL PROPERTIES OF SOILS OF THE AREA

5.1.1 Soil reaction (pH)

The pH of the soils in a portion of GLBC command area (46,029.9 ha) was slightly to moderately alkaline (8.02-8.96). The soils studied come under arid to semi-arid region and hence are not leached. Similar values were reported by Ashok (1996) in black soils of the same area.

5.1.2 Electrical conductivity (EC)

The EC values of the GLBC command area studied were in normal range (0.11–1.40 dS m⁻¹). Ashok (1996) reported similar EC values for the black soils in GLBC command area. Relatively higher values were observed in the study area in the undulating

plains and alluvial plains as salts are expected to be higher in the lower elements of the landscape. Dasog and Hadimani (1980) reported EC ranging from 0.39-0.53 at surface in GLBC soils.

5.1.3 Organic carbon (OC)

The organic carbon content of the soils in the study area ranged from 0.34 to 1.33 per cent and fall under low, medium and high category. Dudal (1965) has reported that organic carbon in Indian soils range from 0.5 to 1.5 per cent. The values obtained in the present study are slightly higher than 0.4 to 0.9 per cent reported by Ashok (1996) in Ghataprabha soils. The higher organic carbon content in these soils is owed to its management practices such as addition of crop residues and cropping pattern followed. Soils of semi-arid region have low organic carbon than sub-humid soils (Jagadish Prasad and Gajbhiye, 1998). The organic matter build up in soils is related to natural vegetation, cropping history and temperature (Dudal, 1965).

5.1.4 Calcium carbonate content

The calcium carbonate content of the soils of GLBC command ranged from 5.13 to 11.55 per cent. Vertisols of India have calcium carbonate content generally ranging from 7.0 to 10.0 per cent (Dudal, 1965). Dasog and Hadimani (1980) reported calcium carbonate ranging narrowly from 10.2 to 16.4 per cent.

surface horizons of GLBC pedons. Calcareous nature of these soils reflect the semi-arid environment in which these soils occur.

5.1.5 Available nitrogen

As depicted in Fig. 3 out of the study area in GLBC (46,029.9 ha), about 58 per cent [GLBC] area was medium in available nitrogen status (26,490 ha), while 42 per cent of the area (19,540 ha) was low in available nitrogen status. Nitrogen is the most limiting nutrient in black soils (Stewart, 1988), which is subjected to losses through leaching and volatilization. The total nitrogen content in the soils is dependent on temperature, rainfall and altitude (Biju Joseph, 1994). The nitrogen status of the soils studied was slightly better than what was reported for the state by Shivaprasad *et al.* (1998). They reported that 35.8 per cent of the soils in Karnataka state was medium in available nitrogen status and that the soils in areas under irrigation and hilly regions of the plateau were medium in available nitrogen status, while rest of the area was low in N content. Medium status for available nitrogen might be due to liberal crop residue addition to the soil, which is generated in large quantities in the study area. In Vertisols, there is a flush of nitrate formation with the onset of monsoon following hot and dry spell. The longer the dry spell, the higher is the formation of mineral and nitrate N (Stewart, 1988). Majority of the samples

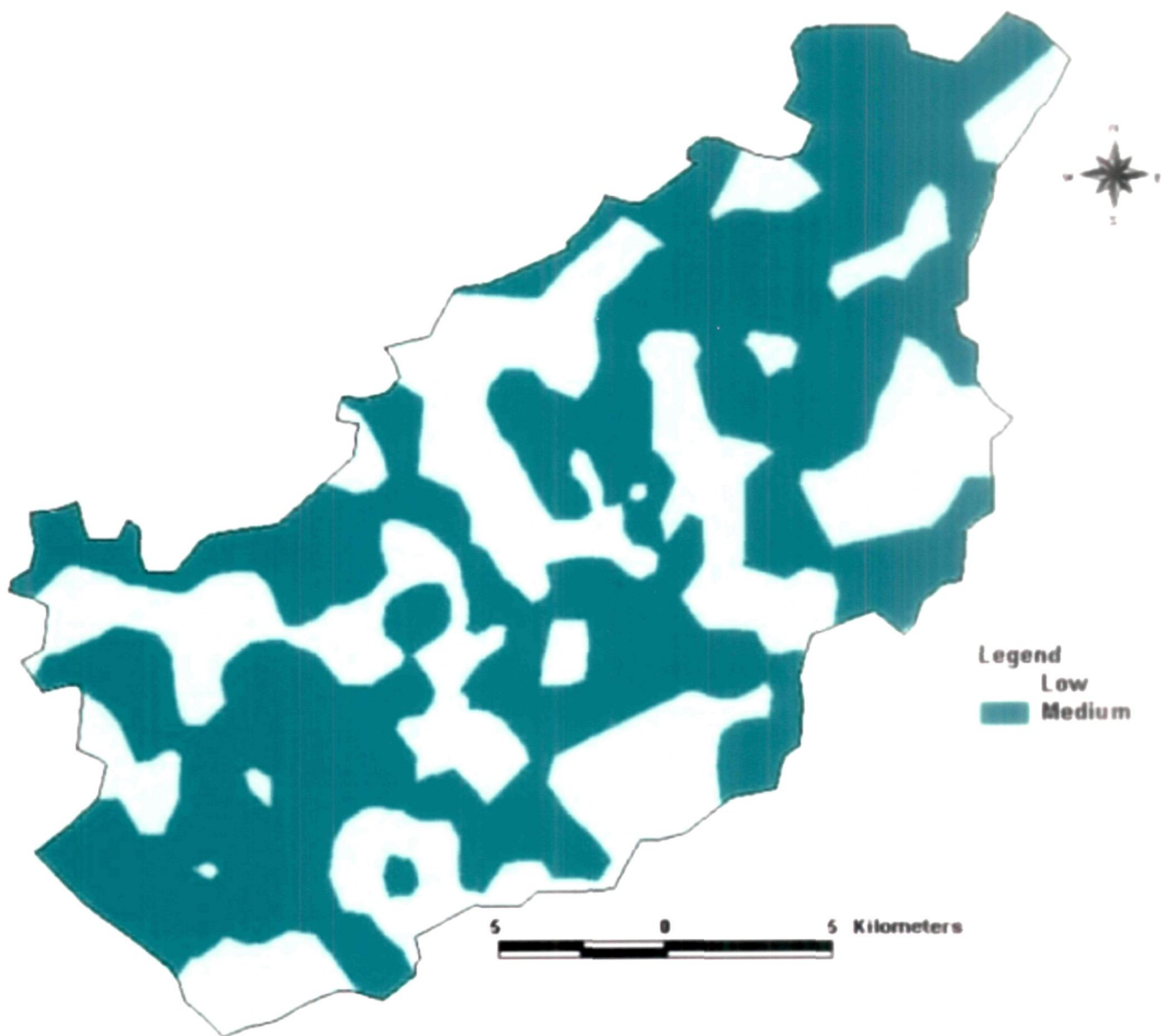


Fig. 3: Available nitrogen status of a portion of GLBC command area

were obtained before rainy season and reflects higher nitrogen levels.

There was poor correlation between organic carbon and available nitrogen content of the soils studied. Therefore, recommendations based on organic carbon alone may not be relevant.

5.1.6 Available Phosphorus

As depicted in Fig. 4 about 25 per cent (11,354 ha) of the GLBC area was medium in available phosphorus content and rest 75 per cent (34,677 ha) of the area was found to be high in P content. Though P is the second limiting element (Stewart, 1988) in Vertisols phosphorus content might have increased in the soils of study area by cultivation and phosphorus fertilization in surface horizons (Stewart, 1988). Fertilizer P is added in high intensity productions systems as is the study area. In contrast to general low levels of P in majority of the Vertisol area, the P levels in the study area are better.

5.1.7 Available Potassium

The soils of the study area of GLBC were found to be high in available potassium status (Fig. 5). Around 88 per cent (40,612 ha) of the GLBC area recorded high K values, while only 12 per cent of the area (5418 ha) had medium available potassium



Fig.4: Available phosphorus status of a portion of GLBC command area

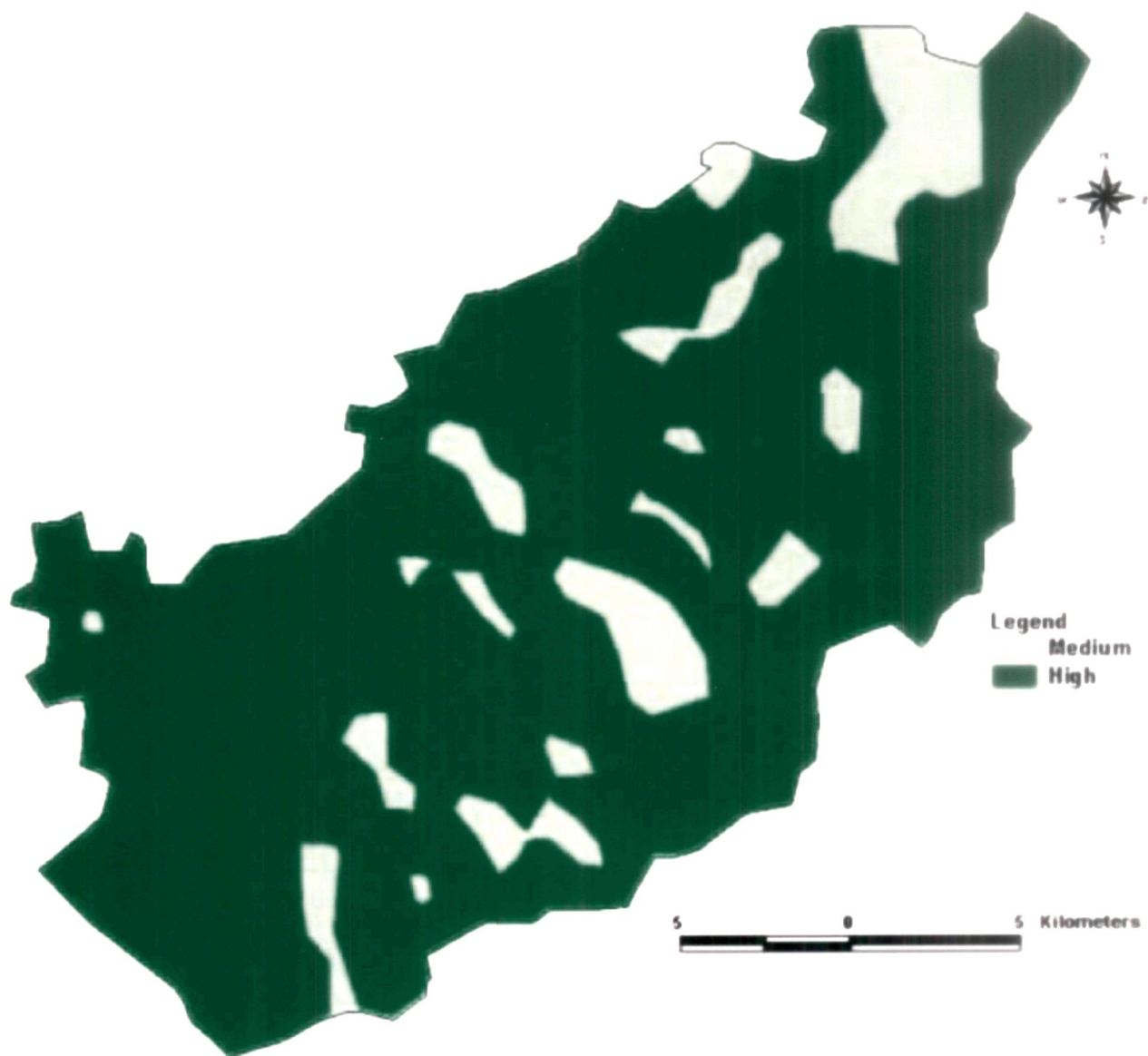


Fig.5: Available potassium status of a portion of GLBC command area

content. Parashivamurthy (1988) and Shivaprasad *et al.* (1998) also reported medium to high K status in black soils of Karnataka. It is observed that many Vertisols are able to maintain a sufficient or even high level of exchangeable K and to provide a good supply of K to plants for many years (Finck and Venkateswarlu, 1982).

5.1.8 Exchangeable calcium and magnesium

All the soils of the study area were high in exchangeable Ca and Mg contents. Ananthanarayana (1978) reported higher exchangeable Ca and Mg content in black soils than red or laterite soils. Availability of calcium and magnesium to the crops do not generally present problems in black soils, as these soils are calcareous. These were determined as a matter of routine to include all the secondary nutrients and to examine the ratio of these to other nutrients especially potassium which was critical. It is stated that Mg deficiency can occur in soils with high ratio of exchangeable Ca/Mg exceeding 10:1 (Tisdale *et al.*, 1995). The ratio observed in the soils studied is well under 1:3 thus there is no possibility of this being happening.

Similarly, high levels of exchangeable K can also interfere with Mg uptake by crops. General recommendations are K/Mg ratio of less than 5 for field crops and less than 3 for vegetables

and sugar beets (Tisdale *et al.*, 1995). The ratios are much less than prescribed in the soils studied.

5.1.9 Available sulphur

Out of 46,029.9 ha of the GLBC command area studied, about 27 per cent of the area (12,420 ha) was low in sulphur content, 69 per cent (31563 ha) was medium and only four per cent (2047 ha) was found to be high in sulphur content (Fig. 6). The values are comparable to those reported by Balanagoudar and Satyanarayana (1990) in some Vertisols of North Karnataka. According to them organic sulphur was more in surface horizons which could be attributed to the higher organic carbon content in surface layers. Devaraj (1994) also observed that fine texture soils are generally well supplied with sulphur. There was a very poor correlation among organic carbon, nitrogen and sulphur content of the soils.

5.2 SOIL FERTILITY STATUS AS AFFECTED BY DIFFERENT PHYSIOGRAPHIC UNITS

The soil fertility status as affected by different physiographic units namely, plateau, hills, undulating plains and alluvial plains are depicted in Fig. 7 to 10.

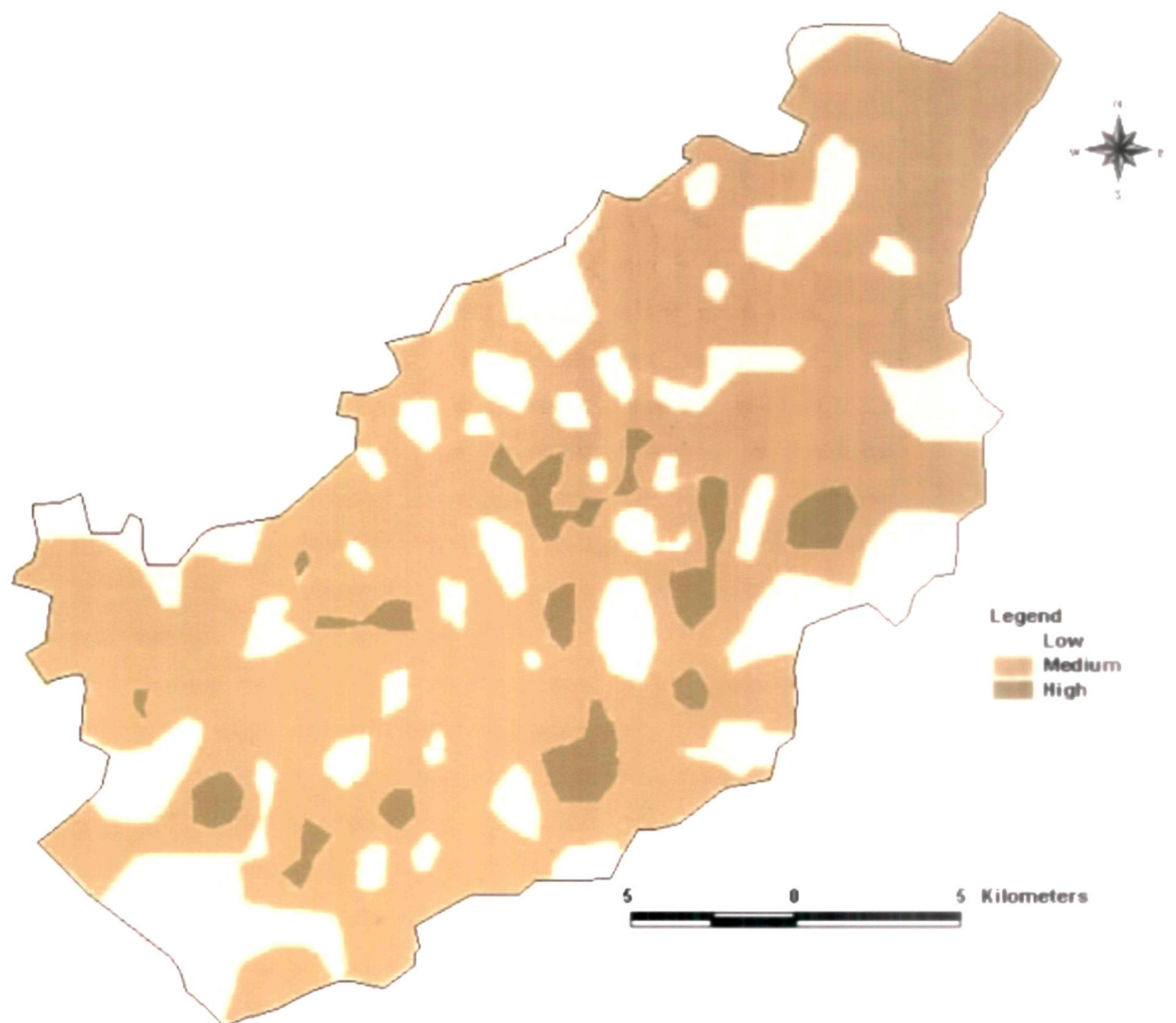


Fig.6: Available sulphur status of a portion of GLBC command area

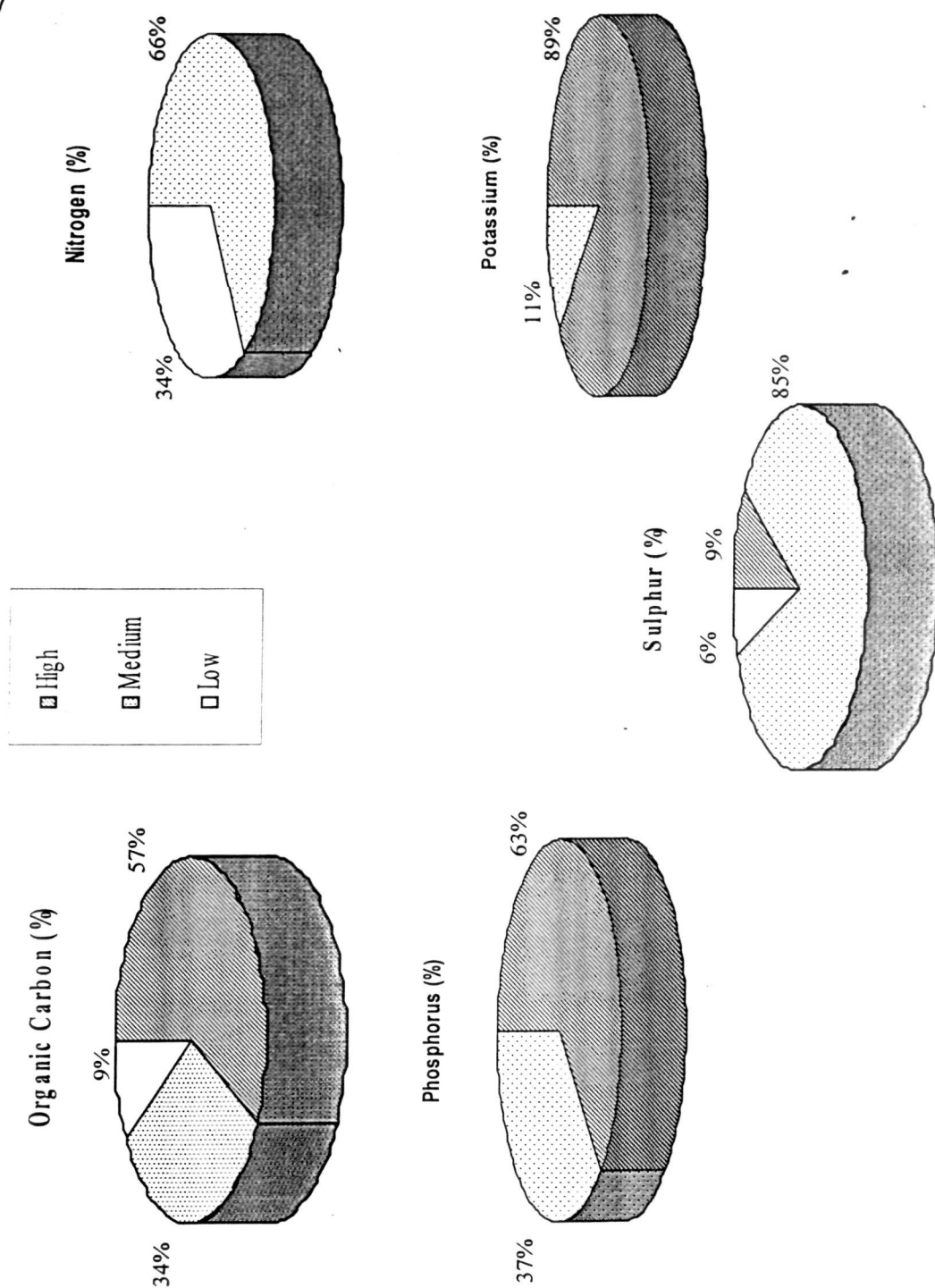


Fig. 7 : Ratings of organic carbon and available nutrients in soils on plateau (GLBC)

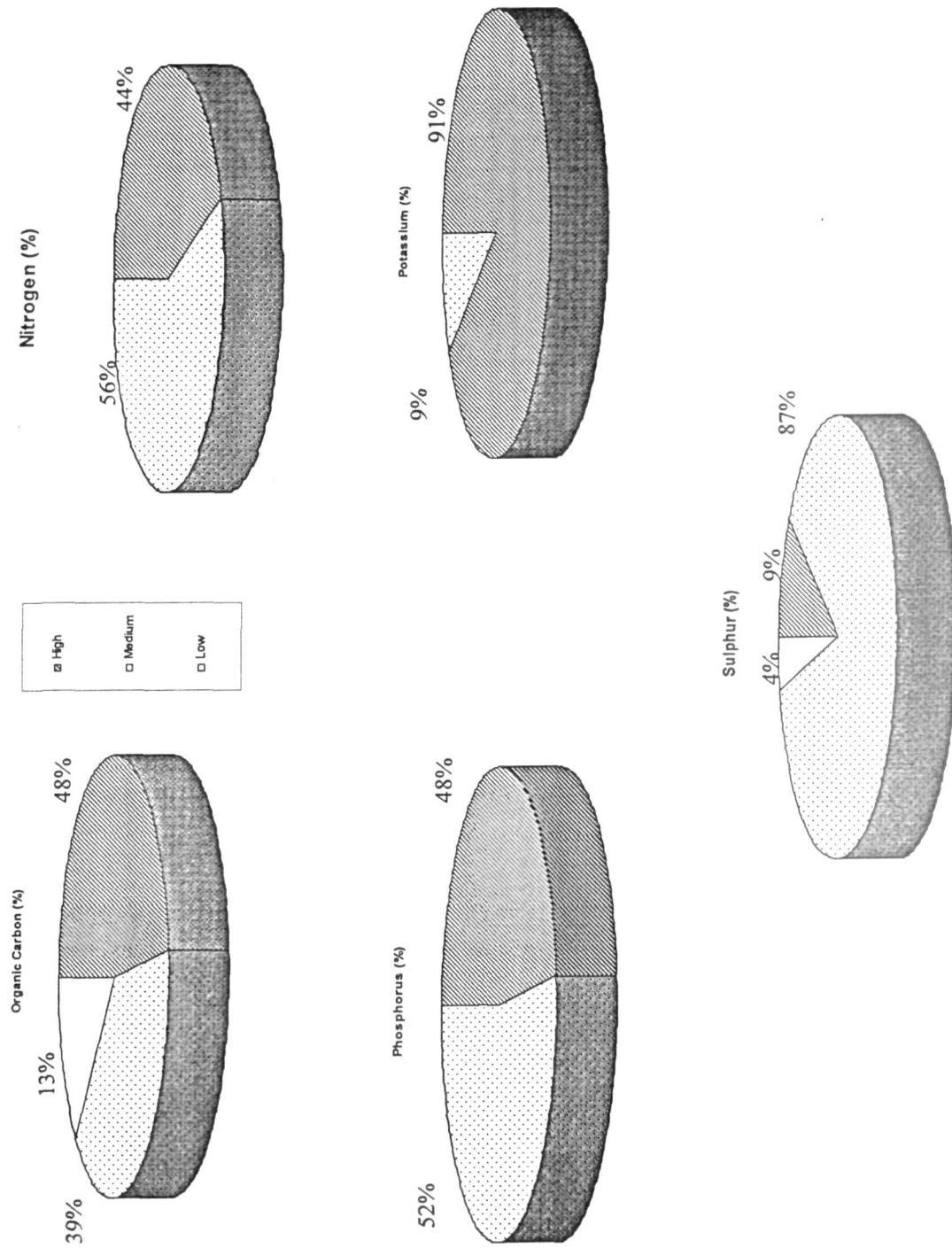


Fig.8 : Ratings of organic carbon and available nutrients in soils on hills

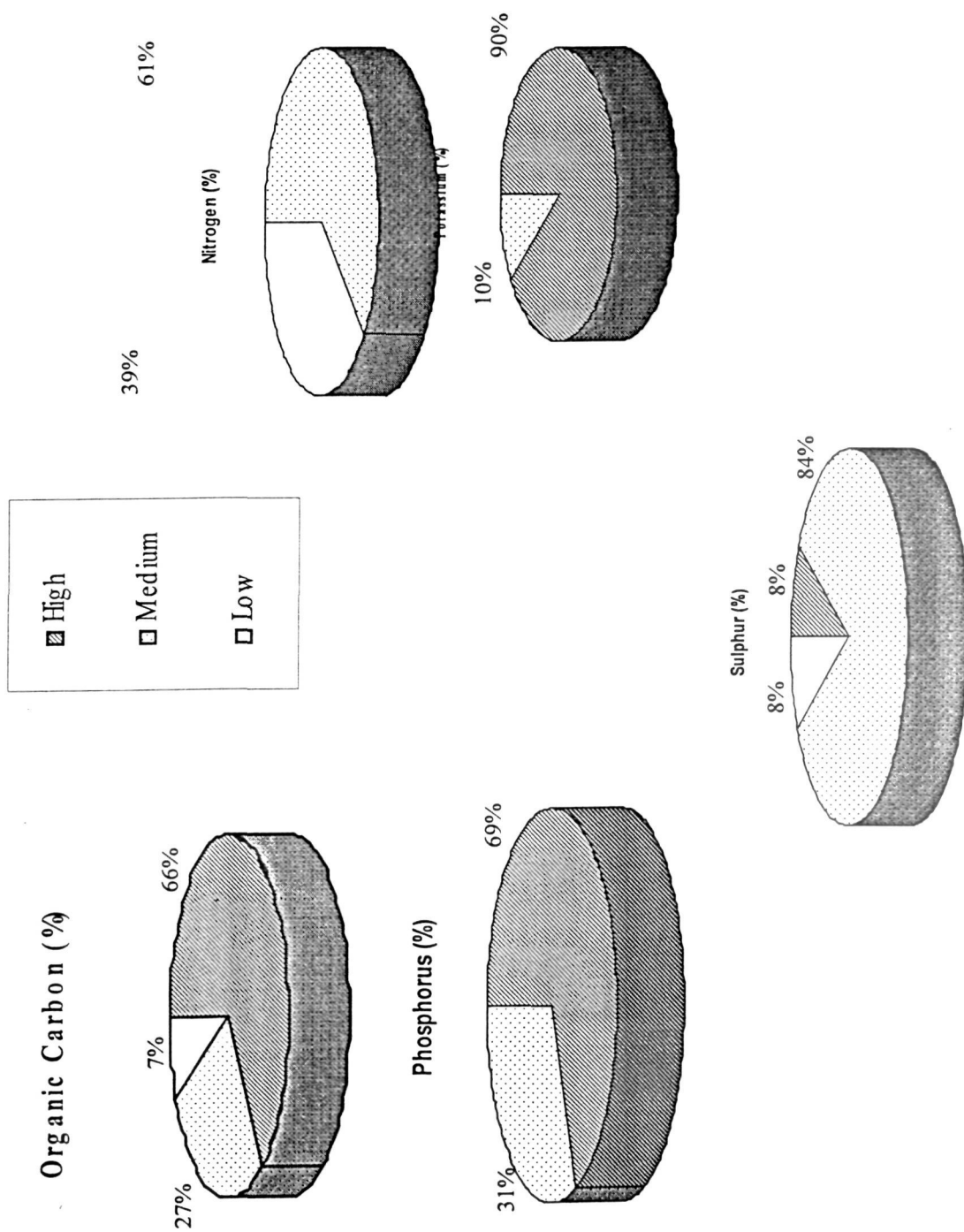


Fig. 9: Ratings of organic carbon and available nutrients in soils on undulating plains

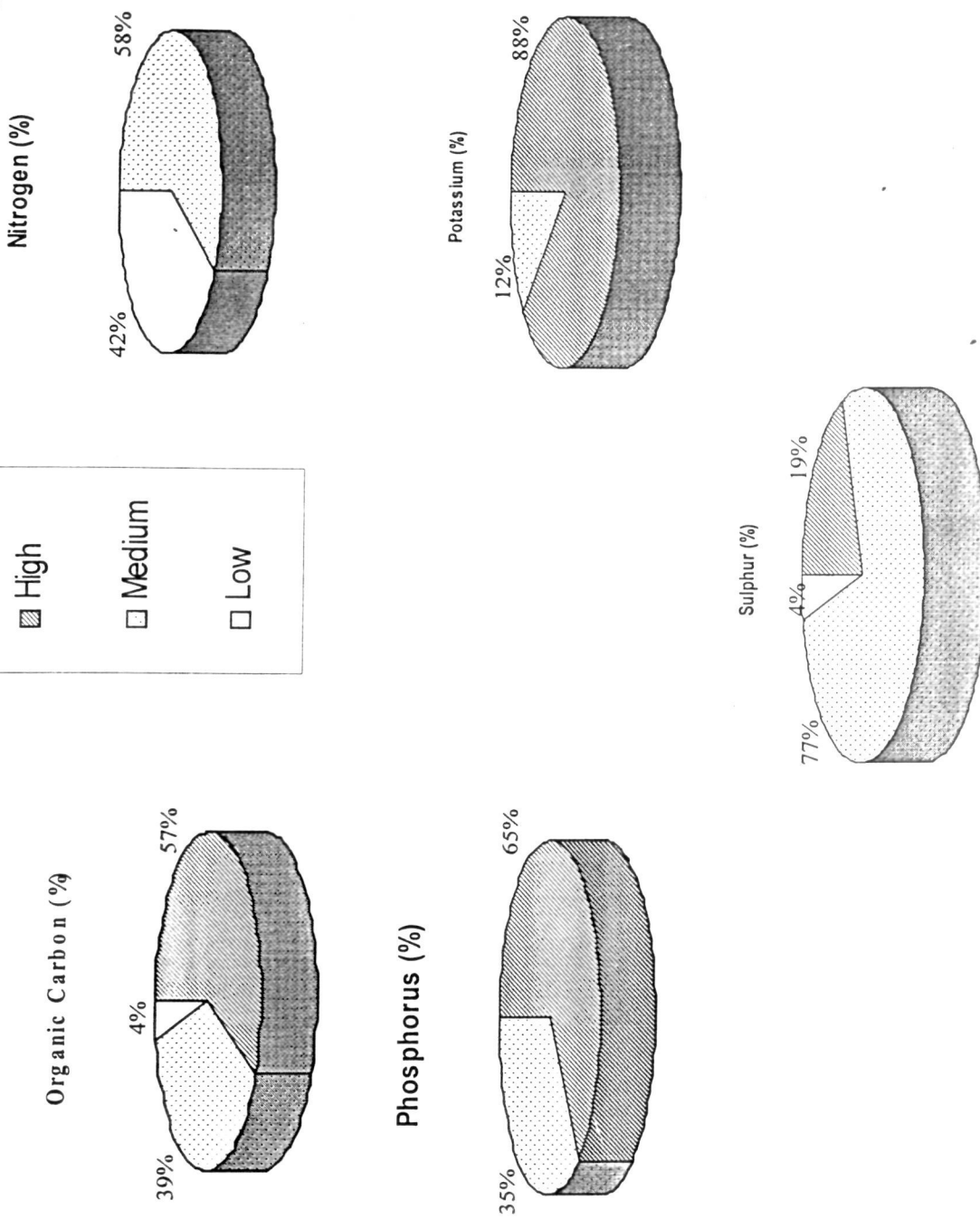


Fig.10 : Ratings of organic carbon and available nutrients in soils on alluvial plain

The mean and standard deviation of most nutrients were remarkably similar irrespective of the physiographic unit. If the data in percentage is taken, some subtle differences exist. For example 66 and 57 per cent of the samples on gently undulating plain and alluvial plain had high organic carbon; the corresponding figures for hills was 48 per cent. Further, in the alluvial plain the samples with low organic carbon were the least in alluvial plain. The lower elements of landscape (Fig. 7, 9 and 10) seem to preserve organic matter by preventing it against oxidation(Hebsur, 1997).

5.2.2 Available nitrogen

With respect to nitrogen, the hilly unit had 56 per cent soils under low and 44 per cent under medium category. Compared to this the other physiographic units had somewhat higher percentage in medium category which was 66, 61 and 58 per cent, respectively for plateau, undulating plain and alluvial plain. Patel *et al.* (1983) reported higher nitrogen in foot hill soils of Girnar in Junagarh. The lack of any trend among the three physiographic units may be due to intensive agriculture practised in all these due to irrigation water availability.

5.2. 3 Available phosphorus

In the hilly unit, the maximum extent of soils under medium and high-class percentage was rather equally distributed as compared to others. In others, however, the high class constituted around two-third samples, thus, bringing about clear difference between hilly and other units. This is largely attributed intensive agriculture practised by way of growing sugarcane and other crops in all but hilly unit. Badanur (1971) also observed that generous application of phosphorus has resulted in phosphorus buildup in soils.

5.2. 4 Available potassium

Available potassium was high in majority of the samples with a few being of medium status. Potassium is commonly reported as high in black soils irrespective of their depths (Hirekurabar, 1998) reported that surface samples were high in available K content (378 to 770 kg ha⁻¹) due to presence of potash rich micaceous minerals. With respect to available potassium all the units exhibited same status in terms of percentage of samples and area.

5.2. 5 Available sulphur

With respect to sulphur again the soils on plateau, hilly and undulating physiographic unit, the percentage exhibited similar

percentage distribution among the three classes of low, medium and high. The alluvial plain, however, the proportion of samples analyzed for high sulphur was more.

5.3 SOIL FERTILITY AS AFFECTED BY CROP COVER

By manually overlapping land use crop cover map on soil fertility map it was seen that crops sugarcane and maize, which are the two important crops of the area cover all physiographic units. This probably is the reason why irrespective of landscape units the nutrient levels are about the same. From the limited data it can be stated that 50 per cent of the soils in soybean grown plots were medium in sulphur and that 50 per cent were low. This may be due to sulphur depletion in soybean plot, soybean being an oil seed crop. While available phosphorus status in these plots were high. This may probably due to high phosphorus fertilization. The sulphur content in cotton growing plots were medium (50 %) while 71 per cent of the soils in these plots recorded high phosphorus content which may probably due to high phosphorus fertilization to these crops.

Due to intensive irrigated agriculture practised in the command area, the nutrient status did not follow any distinct trend with respect to physiographic units, crops and to some extent even soil series. Based on the overall assessment the

nutrient status in these soils is optimum. The information generated in this study could be used for temporal study of soil fertility to compare the fertility status in future.

Summary

VI. SUMMARY

The idea of optimizing the utilization of the land resource with intensification of agriculture has resulted either in the fast depletion of nutrients or occasionally in their accumulation, especially noticed in command areas. Therefore, periodic monitoring of the soil fertility status has become the prime need of the hour. Therefore, an investigation was conducted on soil fertility status of the portion of GLBC command area (46029.9 ha) to evaluate the status of N, P, K, Ca, Mg, and S as affected by the different physiographic units.

Two hundred and forty two samples were collected at random in GLBC command area representing all physiographic positions in the landscape and major crops grown. The area lies between GLBC main canal in the north and Ghataprabha river in the south covering good part of Gokak and some part of Raibag taluk in Belgaum district. The area presented a wide range of elevation ranging between 580 to 640 MSL (mean sea level) has varying geomorphic units. The area was represented by shallow medium and some deep black soils. The crops grown were sugarcane, maize, wheat and vegetables. The fertility maps were prepared for the area using Arc View 3.1 and spatial analyst using spline function for interpolation. The nutrient status was discussed in relation with physiographic position and cropping pattern.

The pH of the soils of the study area was slightly to moderately alkaline (8.02-8.96). The EC of the soils were normal ranging from 0.11 to 1.40 dS m⁻¹ with a mean of 0.36 dS m⁻¹. The samples with higher EC were observed in lower elements of landscape such as undulating plains and alluvial plains.

The organic carbon content of the soils ranged from 0.34 to 1.33 per cent with a mean of 0.79 per cent. The organic carbon content of the soils was observed to be medium to high. Somewhat higher organic carbon in these soils is attributed to addition of sugarcane trash and other crop residues. The calcium carbonate content of the soils in the area ranged from 5.13 to 11.55 per cent.

The available nitrogen status of the soils was low in 19540 ha and medium in 26490 ha. The mean available nitrogen content was 283.6 kg ha⁻¹. The available phosphorus content of the area ranged from 12.0 to 38.0 kg ha⁻¹ with a mean of 23.9 kg ha⁻¹. There was no area in the study area with low available phosphorus. The available phosphorus was medium in 11354 ha and high in 34677 ha. The available potassium content of the soils was high. Its content of the soils ranged from 201 to 689 kg ha⁻¹ with a mean of 426 kg ha⁻¹. The available potassium status was medium in 5418 ha and high in 40612 ha.

The exchangeable calcium and magnesium content in the soils were high as the soils were calcareous. The available sulphur content of the soils of the study area ranged from 17.5 to 53.5 kg ha⁻¹ with a mean of 28.1 kg ha⁻¹. All the three classes were represented with a greater proportion of medium status. The area occupied by low, medium and high sulphur status, respectively is 12420 ha, 31563 and 2047 ha.

There was no appreciable variation in mean and standard deviation between the fertility parameters in relation to the four physiographic units (plateau, hills, undulating plains and alluvial plains). However, if the percentage of samples falling in high, medium and low status in each physiographic unit was seen, there were some subtle differences visible. The hill unit was distinctly different from the rest for most of the parameters.

The variation in nutrient status was not much significant with sugarcane, maize and wheat cropping system. Due to intensive irrigated agriculture practiced in the command area, the nutrient status did not follow any distinct trend with respect to physiographic units and crops grown. Based on the overall assessment the nutrient status in these soils is optimum. The information generated in this study could be used for temporal study of soil fertility to compare the fertility status in future.

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Appendices

Area (ha) under different fertility classes of major and secondary nutrients in GLBC

Nutrients	Area (ha)		
	Low	Medium	High
N	19540	26490	-
P	-	11354	34677
K	-	5418	40612
Ca	-	-	46030
Mg	-	-	46030
S	12420	31563	2047

**SOIL FERTILITY STATUS OF A PART OF GLBC COMMAND
AREA USING GIS**

N. K. BINITHA

2002

Dr. G. S. DASOG
Major Advisor

ABSTRACT

The idea of optimizing the utilization of the land resource with intensification of agriculture has resulted either in the fast depletion of nutrients or occasionally in their accumulation especially noticed in command area. An attempt was made to assess the soil fertility status of a portion of GLBC command area (46029.9 ha) in relation to position of landscape was assessed.

Two hundred and fourty two surface soil samples were collected at random from the study area lying between GLBC main canal and Ghataprabha river representing all physiographic positions of landscape.

The pH of the soils was slightly to moderately alkaline (8.02 to 8.96) and EC at the surface ranged from 0.11 to 1.40 dS m⁻¹ and was slightly on the higher side in alluvial plains. Majority of the soils recorded medium to high OC content ranging from 0.34 to 1.33 per cent. The CaCO₃ content ranged from 5.13 to 11.55 per cent.

The available nitrogen content ranged from 211.0 to 321.6 kg ha⁻¹ with in 19540 ha as low and 26490 ha as medium status. The available phosphorus content ranged from 12 to 38 kg ha⁻¹ with 11354 ha area recording medium and 34677 ha area as high in P status. The available potassium status was high in 40612 ha and medium in 5418 ha area ranging from 201 to 689 kg ha⁻¹.

The exchangeable Ca and Mg content of all the soils were high. The available sulphur content ranged from 17.5 to 53.5 kg ha⁻¹ with 12420 ha area recording low, 31563 ha medium and 2047 ha high in sulphur content.

Due to intensive irrigated agriculture practiced in command area, nutrient status did not follow distinct trend with respect to physiographic units and crops grown.