

**SOIL AND PLANT NUTRIENT CONTENTS IN MANGO
ORCHARDS OF SIRMOUR DISTRICT OF
HIMACHAL PRADESH**

Thesis

by

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CERTIFICATE-I

This is to certify that the thesis entitled, “**Soil and Plant Nutrient Contents in Mango Orchards of Sirmour District of Himachal Pradesh**” submitted in partial fulfillment of the requirements for the award of degree of **Master of Science (Agriculture)** in the discipline of **Soil Science** to Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (HP)-173 230 is a bonafied research work carried out by **Mr. Rohit Chauhan (F-2016-60-M)** son of Sh. Joginder Singh Chauhan under my supervision and that no part of this thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of investigations have been fully acknowledged.

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CERTIFICATE-II

This is to certify that thesis entitled, "Soil and Plant Nutrient Contents in Mango Orchards of Sirmour District of Himachal Pradesh" submitted by Mr. Rohit Chauhan (F-2016-60-M) son of Sh. Joginder Singh Chauhan to Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (H.P.) 173 230 India in partial fulfillment of the requirements for the degree of **Master of Science (Agriculture)** in the discipline of **Soil Science** has been approved by the Advisory Committee after an oral examination of the student in collaboration with the External Examiner.



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Place: Nauli, Solan
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ABBREVIATIONS USED

%	Per cent
Amsl	Above mean sea level
CaCO ₃	Calcium carbonate
cm	Centimeter
cmol (p ⁺) kg ⁻¹	Centimole proton per kilogram
dS m ⁻¹	Deci Siemens per meter
DTPA	Diethylene Triamine Penta Acetic Acid
E	East
EC	Electrical conductivity
<i>et al</i>	Co-workers
etc	<i>et cetera</i>
g	Gram
g kg ⁻¹	Gram per kilogram
H. P.	Himachal Pradesh
ha	Hectare (10,000 m ²)
i.e.	<i>That is</i>
Kg ha ⁻¹	Kilogram per hectare
mg kg ⁻¹	Milligram per kilogram
Mt	Metric tons
°C	Degree Celsius
pH	<i>Puissance de Hydrogen</i>
ppm	Parts per million
viz.	<i>Videlicet</i>

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Chapter-1

INTRODUCTION

Fruits and vegetables are considered to be the protective food because these help to develop defence mechanism in human beings, as they contain adequate amounts of vitamins, minerals, and high quality proteins, which protect us against development of many deficiency disorders.

Mango (*Mangifera indica* L.) is one of the most popular, nutritionally rich fruit with unique flavour, fragrance, taste and health promoting qualities making it a common ingredient in new functional foods often called “Super fruits” as well as “The King of the fruits”. It is an excellent source of vitamin-A and flavonoids like beta-carotene, alpha-carotene and beta-cryptoxanthin. It is an important fruit crop of economic importance in India. The crop occupies an area of 2515.97 thousand ha with a production of 18431.33 thousand MT and ranks first amongst fruits in India. Mango, in Himachal Pradesh, occupies an area of 41.11 thousand ha and 47.61 thousand MT and covers the sub-mountainous parts of Kangra, Hamirpur, Bilaspur and Una district (Anonymous, 2015). The productivity of mango in Himachal Pradesh is far below the national average (7.3 MT/ha) which is mainly attributed to the marginal lands available for mango production, along with constraints such as improper orchard management practices and imbalanced use of fertilizers.

The population of our country is increasing at an alarming rate, thereby putting greater pressure on soil resources. The room for horizontal expansion is very little and the only available option is vertical expansion, through increased productivity and cropping intensity. This can be achieved by using modern technology and intensive cultivation for increased production of quality produce.

Soil is fundamental to crop production. Without soil, no food could be produced on a large scale, nor would livestock be fed. It is a precious gift of nature that requires special care from its users. Many of today’s soil and crop management systems are unsustainable. At one extreme, overuse of fertilizers threatens the sustainability of about 70 per cent of nature and at the other extreme, in most parts of the Asia, the under-use of fertilizers means that soil

nutrients exported with crops are not being replenished, leading to soil degradation and declining yield due to adverse soil health (Hettelingh *et al.*, 2008).

Having the right fertilizer program is critical for efficient tree growth, fruit yield and importantly fruit quality. The objective of fertilizer program is to maintain the soil with adequate nutrition to supply the needs of the trees, as they grow throughout the season. To do this effectively requires an understanding of orchards characteristics (e.g. soil types within the orchard) and an understanding of crop growth stages. The key to mineral nutrition of the plants is the judicious application of fertilizers based on laboratory analysis values. Plant analysis is used to confirm the suspected deficiencies and toxicities of nutrients and also to assess the efficiency of fertilizer treatments. Plants being the best indicators of soil nutrient supply under a given environment and leaf being the centre of nutrition of the plant, therefore, forms the basis of the foliar analysis. If leaf analysis is to serve as a better guide for fertilizer usage planning, in addition to its primary use as a method for assessing the nutritional status of the fruit plants, then it will be desirable to establish and understand the relationship between soil and leaf nutrient contents.

Both soil and leaf analysis are necessary as these are complementary to each other and one supplies the information that the other may not (Awasthi *et al.*, 1998). Physico-chemical characteristics (pH, EC, OC, texture) and the nutrient status of soil are the major parameters, next to climate that governs the growth, productivity and yield of crops. It has been reported that soil characteristics markedly influenced the nutrient availability and ultimately the growth, development and yield of apple trees (Bhandari and Randhawa, 1985).

Soil pH is one of the outstanding chemical characteristics of soil, which influences markedly the availability of nutrients, activity of microorganisms and physical characteristics of soil such as structure and permeability (Brady, 1996). Plants suffer nutrient deficiency stress when availability of soil nutrients is below that required for sustaining metabolic processes in a particular growth stage. This may result from an inherently low nutrient status of soil, low mobility of nutrients within soil, poor solubility of the given form of the nutrient or the soil- microbe- plant interactions (Rengel, 2015).

Soil nutrition of mango is an important part of orchard management practices (Ravishankar *et al.*, 2010). Macro and micronutrients play a vital role in promoting plant vigour and productivity (Takkar,1996). Stino *et al.*, (2011) noted that micronutrients

deficiency also became limiting factor for growth which led to low yields and reduced fruit quality.

The continuous nutritional diagnosis through soil and leaf analysis can be a useful tool to set proper fertilizer programs. Therefore, sound knowledge of status of available major and micronutrients and their interrelationship with soil characteristics is helpful in understanding the inherent capacity of soil to supply the nutrients to plants. No systematic attempt has so far been made to assess the soil and plant nutrient contents of mango growing regions of Sirmour district. Therefore, the study entitled “**Soil and Plant Nutrient Contents in Mango Orchards of Sirmour District of Himachal Pradesh**”, was carried out with the following objectives:

- i) To study the nutritional status of Mango orchards of Sirmour district.
- ii) To study the relationship amongst the different soil characteristics, available soil and leaf nutrient contents.

Chapter-2

REVIEW OF LITERATURE

The rapid increase in the population has led to an increased demand for land, water and food. To meet the basic needs, human kind is degrading these natural resources through unscientific exploitation and causing environmental problems. Modern day fruit cultivation often requires a greater degree of management and larger input of nutrients and irrigation.

At present, fertilizer application rates in intensive agricultural systems have increased dramatically. These high fertilizer inputs and the extremely low crop recoveries of fertilizer nutrients lead to marked deterioration in soil health. To add to that, problems like multi-nutrient deficiencies, especially micronutrients, have further resulted in low crop yields. Crop responses to fertilizers depend on many factors and the fruit yield and quality are decided primarily by the soil and plant nutrient contents in the orchards. There is a meagre information on this aspect and this chapter reviews the relevant literature under following heads:

2.1 Soil Fertility Status

2.1.1 Chemical properties of the soils

2.1.2 Macronutrients

2.1.3 Micronutrients

2.2 Macro and micronutrient concentration in plants

2.3 Relationship of soil properties with nutrient content in soils

2.4 Relationship of soil nutrient contents with plant nutrients and yield

2.1 SOIL FERTILITY STATUS

2.1.1 Chemical properties of soil

Soil chemical properties are the most important among the factors that determine the nutrient supplying power of the soil to the plants and microbes. The chemical reactions that occur in the soil affect processes leading to soil development and soil fertility build up. Minerals inherited from the soil parent materials, over time, release chemical elements that undergo various changes and transformations within the soil.

2.1.1.1 Soil pH

Soil reaction (usually expressed as pH value) affects nutrient availability and toxicity, microbial activity, and root growth. Thus, it is one of the most important chemical characteristics of the soil solution because both higher plants and microorganisms respond so markedly to their chemical environment.

The pH values were found to increase with depth, possibly due to leaching of bases (Kaistha *et al.*, 1990; Sahu and Patnaik, 1990 and Walia and Rao, 1996).

Several workers (Walia and Chamuah, 1990; Gangopadhyay *et al.*, 1990; Verma *et al.*, 1990; Sahu and Patnaik, 1990) reported that pH values of soils ranged from 4.3 to 9.9 in different regions of the country. In the central Himalayas of Himachal Pradesh the pH values varied from 6.7 to 7.7 (Kaistha and Gupta, 1993), whereas, in the mid altitude of outer Himalayas, the pH ranged from 6.5 to 8.4 (Singh *et al.* 1991) and 5.1 to 9.8 in the soils of North-Western Himalayas (Kaistha *et al.* 1990; Sahu and Patnaik, 1990).

Tripathi *et al.*, (1992) reported that the pH of the soils of Mandi district ranged from acidic to slightly alkaline (pH 5.2 to 7.8). Minhas *et al.* (1997) in their studies revealed that the pH in the cultivated soils of Palampur (Kangra district) and Ahju (Mandi district) ranged from 5.3-6.5. The soils of Darang, Palampur and Ahju were less acidic because of their location at relatively lower altitude (about 1200 m) and have lower amount of organic carbon in the surface horizon.

Gangopadhyay *et al.* (1998) found that paddy growing soils of Assam were moderately acidic at the surface (pH 4.7 to 5.7) and slightly acidic to nearly neutral in the sub-surface pH (5.0 to 6.8). Chaudhary *et al.* (2005) categorized soils of Himachal Pradesh as slightly acidic (pH 6.0) to mildly alkaline (pH 8.3) and values increased with depth which might be due to the decrease in organic carbon content. The soils of mid Shivalik hills in Himachal Pradesh were slightly acidic to slightly alkaline (6.52 to 7.74) in reaction (Verma and Tripathi, 2007). However, Sharma and Kanwar (2010) reported that in the soils of dry temperate zones of Himachal Pradesh, pH ranged from 6.2 to 10.3 with a mean value of 7.6.

Chandel (2013), while studying the polyhouse soils of Mandi, Solan and Sirmaur districts, reported the soil pH to range from 6.1 to 7.7, which was higher under polyhouse condition than open condition.

2.1.1.2 Electrical Conductivity

Soil electrical conductivity (EC), a measure of salt concentration, is considered an easily measured, reliable indicator of soil quality/health. It reflects the trends in salinity, crop performance, nutrient cycling (particularly nitrate) and biological activity and along with pH, can act as a surrogate measure of soil structural decline especially in sodic soils (Arnold *et al.*, 2005).

Tripathi *et al.* (1992) reported the soils of apple orchards of Mandi district had an electrical conductivity in the range of 0.16 to 0.94 dS m⁻¹.

Singh *et al.* (2005) found that EC varied from 0.16 to 0.35 dS m⁻¹ in surface and from 0.09 to 0.22 dS m⁻¹ in the sub surface soils of Uttaranchal and decreased with increasing depth. Verma and Tripathi (2007) reported that soils of mid Shiwalik hills in Himachal Pradesh were very low in soluble salt concentration with EC values ranging from 0.01 to 0.15 dS m⁻¹.

Chandel (2013) observed the EC values under polyhouse conditions were within the safe range and varied from 0.19 – 1.70 dSm⁻¹, but were markedly higher as compare to the open conditions.

2.1.1.3 Soil Organic Carbon

The studies carried out by Singh and Datta (1988), Lahiri and Chakravarti (1989), Gangopadhyay *et al.* (1990) and Mandal *et al.* (1990) indicated an increase in organic carbon content with the increase in elevation. It was further observed that organic carbon content was high in the surface horizons which sharply decreased in the sub surface horizons of the profiles.

Organic carbon content was reported to vary from 0.3 to 8.3 per cent in the soils of different regions of Himachal Pradesh (Kaistha *et al.* 1990). Moderately high amount of organic carbon (1.40 to 2.58 per cent) was recorded in the mid-altitude soils of outer Himalayas. The organic carbon content in the surface horizons of forest soils increased with increase in altitude (0.9 to 3.6 per cent) (Singh *et al.* 1991). Tripathi *et al.* (1992) reported that organic carbon content in the soils of Mandi district ranges from 0.20 to 2.6 per cent

Kaistha and Gupta (1993) and Minhas *et al.* (1997) reported that organic carbon content decreased with increasing soil depth. The increase in organic carbon content with increase in altitude was due to continuous addition of leaf litter and slow decomposition of organic residues under low temperature. The cultivated soils of Palampur and Ahju in Kangra district of Himachal Pradesh contained lower amounts of organic carbon.

Sarkar and Sahoo (2000) found that organic carbon content of the soils varied from 0.08 to 0.86 per cent which decreased gradually with depth in Indo-Gangetic plains of Bihar.

Verma and Tripathi (2007) studied the status of soils of mid Shivalik hills in Himachal Pradesh and reported that these soils, in general, contains invariable high amount of organic carbon which ranged from 0.10 to 2.77 per cent.

Najar *et al.* (2009) found the organic carbon content in north facing pedons to vary from 0.16 to 3.5 per cent, whereas, in southern aspect it ranged from 0.1 to 2.4 per cent, in the apple growing soils of Kashmir Valley. The organic carbon content in soils of dry temperate zone of Himachal Pradesh varied from 0.42 to 4.08 per cent (Sharma and Kanwar, 2010).

Devi and Kumar (2010) found that the organic carbon content in the surface layer of the profiles of coffee growing soils of Karnataka ranged from 1.47 to 5.29 per cent which decreased with depth. The polyhouse soils in mid-hill zone of Himachal Pradesh have an organic carbon content varying from 0.64 – 3.48 per cent (Chandel, 2013).

The literature clearly indicates a significant variation in organic carbon content and shows a decreasing trend in its content with increase in soil depth.

2.1.2 Macro Nutrients

2.1.2.1 Available Nitrogen

Nitrogen is the fourth plant nutrient taken up by plants in greatest quantity next to carbon, oxygen and hydrogen, but it is one of the most deficient elements in the tropics for crop production (Sanchez, 1976; Mengel and Kirkby, 1987; Mesfin, 1998). The total N content of a soil is directly associated with its organic carbon content, and its amount on cultivated soils is between 0.03 to 0.04 per cent by weight (Mengel and Kirkby, 1987; Tisdale *et al.*, 1995).

Ramamoorthy and Bajaj (1969) reported that the soils of India were low in available N. The cultivated soils of Seeraj and Karsog blocks in Mandi district of Himachal Pradesh have been found to be medium in available nitrogen (Thakur *et al.*, 1971). Verma *et al.* (1976) reported that the cultivated soils of Kangra district of Himachal Pradesh were low in available nitrogen.

Ghosh and Hasan (1980) prepared a map of nitrogen status of Indian soils and found that many soils of hill regions including Himachal Pradesh were high in available N, while those of plains were low to medium in N status.

The available nitrogen content has been reported to vary from 113 to 228 kg ha⁻¹ in Una and Hamirpur soils, and 295 to 503 kg ha⁻¹ in Kangra, Mandi, Bilaspur, Shimla and Sirmour district soils of Himachal Pradesh (Verma and Tripathi, 1982).

Raina (1988) studied the citrus growing soils of Poanta valley of Himachal Pradesh and reported the soils to be low in available N. Singh and Datta (1988) for the Mizoram soils and Kaistha *et al.* (1990) for soils of North Western Himalayan region, found a decreased content of different forms of available N with the increase in profile depth. The higher content of organic carbon in the surface layers was responsible for higher nitrogen content.

Brar (1998) reported that soils of Punjab were deficient in available N. Sharma *et al.* (1998) found the soils of Loon watershed of Kangra district as medium in available N status.

For Indian soils, 51, 36 and 59 per cent soils were high, medium and low, respectively, in available N (Anonymous, 2001). Mahajan (2001) reported that soils of Mandi district in Himachal Pradesh as medium in available N (384 to 492 kg ha⁻¹).

Motsara (2002) reported that out of 36,50,004 samples of Indian soils, per cent soil samples which fell in low, medium and high categories were 63, 26 and 11, respectively, in case of available N. Sharma *et al.* (2002) reported that soils of Fatehpur block in Himachal Pradesh were low to high in available N. Sharma and Kumar (2003) reported that soils of agricultural lands of mid-hill zone of Himachal Pradesh were medium to high in available N.

Tandon (2004) reported that about 63 per cent of Indian soils were low in available N. Kumar and Verma (2005) studied the fertility status of rice growing soils of Palam valley of Himachal Pradesh and reported that the soils were low to medium in available N.

Laxminarayan (2006) reported that available nitrogen content varied from 213 to 452 kg ha⁻¹ in the soils of Mizoram. The soils of Chattha area of Jammu were low in available N. Agricultural lands had better fertility status with respect to nitrogen as compared to non agricultural lands (Mondal *et al.*, 2007).

In the sweet orange growing soils of Jalna District of Maharashtra, Dhale and Prasad (2009) found that available nitrogen content varied from 68 to 330 kg ha⁻¹. The available nitrogen content of Andhra Pradesh soils varied from 133 to 188 kg ha⁻¹ and the content decreased with depth (Rajeshwar *et al.*, 2009).

Kumar and Prasad (2010) characterized the sugarcane growing soils of Maharashtra and found the soils to be medium in available N. Sahoo *et al.* (2010) characterized the fertility status of agricultural lands of Manipur and rated the soils as medium to high in available N (503 to 1078 kg ha⁻¹). Shilpashree *et al.* (2011) revealed that soils of arecanut gardens in Karnataka were medium in available N.

Sharma and Kanwar (2012) reported maximum nitrogen deficiency in the soils of Gondhla valley (73 per cent), followed by Kinnaur (48 per cent), Spiti (46 per cent), Pattan valley (43 per cent) and Udaipur valley (28 per cent). Chandel (2013) observed that the polyhouse soils of Mandi, Solan and Sirmaur districts had nitrogen levels ranging from 200.7 – 359.3, 194.4 – 388.9 and 307.3 – 476.7 kg ha⁻¹, respectively.

The literature clearly indicates that available nitrogen content varied from low to medium in the country. The available nitrogen content decreased with increasing soil depth and, in general, higher available N content was found in the surface horizons.

2.1.2.2 Available phosphorus

Ramamoorthy and Bajaj (1969) reported that the soils of India were low in available P. The cultivated soils of Seeraj and Karsog blocks in Mandi district and those of kangra region of Himachal Pradesh were low in available P (Thakur *et al.* 1971, Verma *et al.* 1976).

Ghosh and Hasan (1979) reported that the available P status of Indian soils is medium, low and high to the extent of 52, 46 and 2 per cent, respectively.

The content of available P varied from 2.69 to 28.22 kg ha⁻¹ in the soils of Kangra, Kullu, Mandi and Sirmour areas of Himachal Pradesh (Verma *et al.* 1985). Jha *et al.* (1988) reported that available P₂O₅ content increased with the increase in clay content of soil profiles. The study conducted by Lahiri and Chakravarti (1989) indicated that the available phosphorus content is medium range in Sikkim soils.

Raina (1988) studied the citrus growing soils of Poanta valley of Himachal Pradesh and reported that the soils are medium to high in available P. A decrease in available phosphorus with increase in soil depth has been reported by various workers (Sood *et al.* 1991; Dongale, 1993). Available P status was found to be low in Dehra, Nurpur, Lambagaon, Badsar and Sundernagar blocks of Himachal Pradesh (Anonymous, 1993). Patgiri and Datta (1993) have reported that available phosphorus content varied from 13.44 to 20.16 kg ha⁻¹ in tea growing soils of Assam.

Khan *et al.* (1997) reported that available phosphorus was high in the surface and decreased downward in the profile. Sharma *et al.* (1998) found the soils of Loon watershed of Kangra district were medium in available P status.

Powar and Mehta (1999) noticed that the available phosphorus of lateritic soils of Konkan Coast varied from 1.25 to 25.50 and 2.25 to 28.75 kg ha⁻¹ in surface and sub-surface soils, respectively. Bharambe *et al.* (2001) reported that the available phosphorus of Majalgaon Canal Command Area of Maharashtra varied from 9.6 to 24.0 kg ha⁻¹ in surface layers, indicating a low to medium available phosphorus status.

Pandey *et al.* (2000) reported wide variability in the availability of P in different soil associations of district Kanpur in Uttar Pradesh. Contents of available P ranged from 7.7 to 55.4 kg ha⁻¹ and correlation studies revealed that availability of P was significantly and positively influenced by organic matter and finer soil particles.

Out of the total samples analysed, 6, 45 and 49 per cent of Indian soils were high, medium and low in available P (Anonymous, 2001). Mahajan (2001) reported that the soils of Mandi district in Himachal Pradesh were medium in available P (17 to 22 kg ha⁻¹). However,

Sharma *et al.* (2001) reported that majority of the soils of Himachal Pradesh were deficient in P. Motsara (2002) reported that out of 36,50,004 samples of Indian soils, soil samples analysed for available P which fell in low, medium and high categories were 42, 38 and 20 per cent, respectively.

Sharma *et al.* (2002) reported that soils of Fatehpur block in Himachal Pradesh were low to high in available P, whereas, Sharma and Kumar (2003) reported that soils of agricultural lands of mid-hill zone of Himachal Pradesh were low to medium in available P.

Tandon (2004) reported that about 44 per cent of Indian soils were low in available P. Kumar and Verma (2005) studied the fertility status of rice growing soils of Palam valley of Himachal Pradesh and reported that the soils were low to medium in available P.

Chand *et al.* (2006) reported that available phosphorus content varied from 5.8 to 63.9 kg ha⁻¹ in soils of Punjab. Tripathi *et al.* (2007) studied the status of nitrogen, phosphorous and potassium in the hill soils of North-Western Himalayas. The mean phosphorous content was found to be 28 kg/ha. Chandel (2013) reported that the polyhouse soils of Mandi, Solan and Sirmaur districts had phosphorus levels ranging from 38.08 – 91.84, 58.24 – 145.50 and 58.24 – 147.84 kg ha⁻¹, respectively.

Available phosphorus shows wide variation in its content at different locations of the country. In general, available phosphorus followed a decreasing trend with increase in soil depth.

2.1.2.3 Available potassium

Ramamoorthy and Bajaj (1969) reported that the soils of India were medium in available K. Thakur *et al.* (1971) found that the cultivated soils of Seeraj and Karsog blocks in Mandi district of Himachal Pradesh were low in available K.

Ghosh and Hasan (1976) in their studies of Indian soils found 42, 38 and 20 per cent soils to be medium, high and low in available K, respectively. Further, Verma *et al.* (1976) reported that the cultivated soils of Kangra district of Himachal Pradesh were low in available K. Verma *et al.* (1985) further characterized the soils of Kangra, Kullu, Mandi and Sirmour areas of Himachal Pradesh and found the contents of available K ranging from 40.26 to 1507

kg ha⁻¹. Raina (1988) reported medium levels of K in the citrus growing soils of Poanta valley of Himachal Pradesh.

Lahiri and Chakravarti (1989) recorded low available potassium content in the soils of Sikkim which ranged between 8.96 to 41.87 kg ha⁻¹. Tripathi *et al.* (1992) reported that concentration of exchangeable potassium ranged from 0.11 to 1.74 me 100g⁻¹, in the soils of Himachal Pradesh.

Alluvial soils of Assam contained relatively higher amount of potassium (Basumatary and Bordoloi 1992). Khan *et al.* (1997) found slightly higher concentration of available potassium in the upper horizons of the pedons. Sharma *et al.* (1998) found the soils of Loon watershed of Kangra district are medium in available K status.

Powar and Mehta (1999) noticed that available potassium content of soils of Konkan coast (Maharashtra) varied from 130 to 350 kg ha⁻¹ in surface soils. Bharambe *et al.* (1999) reported that available potassium content on Majalgaon Canal Command Area of Maharashtra varied from 508 to 1321 kg ha⁻¹, indicating high potassium content.

In Indian soils, 52, 39 and 9 per cent samples were high, medium and low in available K (Anonymous 2001). Mahajan (2001) found medium levels of potassium (231 to 235kg ha⁻¹) in soils of Mandi district of Himachal Pradesh.

Motsara (2002) reported that out of 36,50,004 samples, 13, 37 and 50 per cent soil samples fell in low, medium and high categories, respectively, in case of available K. Sharma *et al.* (2002) reported that soils of Fatehpur block in Himachal Pradesh were low to medium in available K.

Sharma and Kumar (2003) reported that the soils of agricultural lands of mid-hill zone of Himachal Pradesh were low to high in available K. Tandon (2004) reported that about 21 per cent of Indian soils were low in available K.

Kumar and Verma (2005) studied the fertility status of rice growing soils of Palam valley of Himachal Pradesh and reported that the soils were low to high in available K. Tripathi *et al.* (2007) studied the status of nitrogen, phosphorous and potassium in the hill soils of North-Western Himalayas and found a mean potassium content of 289 kg ha⁻¹.

Shetty *et al.* (2008) reported that the majority of Karnataka soils were medium in available potassium. Vara Prasad Rao *et al.* (2008) characterized the grassland soils of Andhra Pradesh as medium to high in available K. Dhale and Prasad (2009) while characterizing and classifying the sweet orange growing soils of Jalna district of Maharashtra found that available potassium content ranged from 195 to 1287 kg ha⁻¹. In the soils of Andhra Pradesh, available potassium content varied from 110 to 389 kg ha⁻¹ and it decreased with depth (Rajeshwar *et al.*, 2009).

Kumar and Prasad (2010) characterized the sugarcane growing soils of Maharashtra and found medium to high content of potassium. Sahoo *et al.* (2010) characterized the fertility status of agricultural lands of Manipur and rated the soils as low to high in available K (79 to 440 kg ha⁻¹). Shilpashree *et al.* (2011) revealed that soils of arecanut gardens in Karnataka were medium in available K.

Sharma and Kanwar (2012) reported nearly 83 per cent of the soil samples to be high in available potassium. In general, available potassium showed a decreasing trend with soil depth. Chandel (2013) observed that the polyhouse soils of Mandi, Solan and Sirmaur districts had potassium levels ranging from 224.00 – 1039.4, 227.40 – 776.2 and 229.60 – 902.72 kg ha⁻¹, respectively.

2.1.2.4 Calcium

Exchangeable calcium was found to vary from 2.2 to 10.5 [cmol (p⁺) kg⁻¹] in the soils of North-West Himalaya (Gupta and Tripathi, 1989), 3.7 to 15.3 [cmol (p⁺) kg⁻¹] in the soils of Central Himalaya of Himachal Pradesh representing sub humid temperate highlands (Kaistha and Gupta, 1993) and 2.1 to 20.0 [cmol (p⁺) kg⁻¹] in the wet temperate zone soils of Himachal Pradesh (Minhas *et al.*, 1997).

Nair and Chamuah (1988) and Bala and Sahu (1993) found exchangeable calcium as dominant cation in the soils of pine forest of Himachal Pradesh and middle Andaman and Orissa, respectively and on an average exchangeable calcium accounted for 70 -80 per cent of the exchange capacity.

Mahajan (2001) reported the soils of Mandi district in Himachal Pradesh as high in exchangeable Ca (4.0 to 5.1 [cmol (p⁺) kg⁻¹]). Sharma *et al.* (2001) reported that majority of

soils of Himachal Pradesh were deficient in Ca. Sharma *et al.* (2002) reported that soils of Fatehpur block in Himachal Pradesh were sufficient in exchangeable Ca.

Dhale and Prasad (2009) characterized and classified sweet orange growing soils of Jalna district of Maharashtra and found the exchangeable Ca content to vary from 24.48 to 55.61 [cmol (p⁺) kg⁻¹]. Shilpashree *et al.* (2011) revealed that soils of arecanut gardens in Karnataka were sufficient in Ca.

The literature clearly indicates a significant variation in exchangeable calcium content. In general, higher exchangeable calcium content was reported under high rainfall areas and Ca content decreased with depth.

2.1.2.5 Magnesium

Sankhyan (1972) observed no relationship of exchangeable magnesium content with the depth of the soils in Saproon valley of Himachal Pradesh. Lombion (1979) while evaluating the Mg supplying power of Nigerian soils found Mg content to vary from 0.43 to 0.74 [cmol (p⁺) kg⁻¹] and rated these soils as low in exchangeable Mg. Singh and Raman (1982) observed a decreasing trend of exchangeable magnesium with the increase in soil depth in the North-Eastern Himalayan soils. Mandal *et al.* (1990) have reported exchangeable Mg content to be related to organic carbon and CaCO₃ content in the soils of upper hill forest of eastern Himalayan soils. Singh *et al.* (1991) in their study on mid-Shiwalik and North-West Himalayan soils reported surface soils as poor in Mg than the sub-surface soils.

Exchangeable magnesium varied from 0.1 to 4.2 [cmol (p⁺) kg⁻¹] in the soils of Central Himalayas of Himachal Pradesh representing sub-humid temperate highlands (Kaistha and Gupta, 1993), 0.7 to 10.5 [cmol (p⁺) kg⁻¹] in the soils of North-Western Himalayas (Gupta and Tripathi, 1996) and 1.0 to 6.6 [cmol (p⁺) kg⁻¹] in the soils of Assam valley (Bhattacharya *et al.*, 1997).

Mahajan (2001) reported the soils of Mandi district in Himachal Pradesh as high in Mg (1.7 to 2.4 [cmol (p⁺) kg⁻¹]). Sharma *et al.* (2001) reported that majority of soils of Himachal Pradesh were deficient in Mg. Sharma *et al.* (2002) reported that soils of Fatehpur block in Himachal Pradesh were sufficient in exchangeable Mg.

Shekhar (2009) observed that exchangeable magnesium content in surface soils of forest, grassland and cultivated lands of high rainfall areas in Kangra, Chamba and Mandi

districts of Himachal Pradesh varied from 0.63 to 1.03, 0.36 to 0.75 and 0.75 to 0.88 [cmol (p⁺) kg⁻¹], and respective values in sub surface soils were 0.40 to 0.93, 0.20 to 0.65 and 0.59 to 0.79 [cmol (p⁺) kg⁻¹].

The literature clearly indicates a significant variation in exchangeable Mg content and its content decreased with soil depth.

2.1.2.6 Sulphur

Tripathi and Singh (1992) reported that soluble sulphate sulphur content ranged from 5.5 to 21.2 mg kg⁻¹ and shows a decreasing trend with the depth. Low content of this form was recorded in sub-surface horizons. Pandey *et al.* (2000) reported that wide variability in the availability of S was observed in different soil associations of district Kanpur in Uttar Pradesh. Available S contents varied from 5.8 to 53.8 mg kg⁻¹. In correlation studies S availability was found significantly and positively affected by organic matter, CEC, and finer soil particles. According to Anonymous (2001) 20 to 25 per cent of soil samples studied were deficient in available S. Tripathi and Singh (1992) also reported that sulphate and organic carbon shows a highly significant ($r=0.68^{**}$) correlation in the soils of Himachal Pradesh.

Sharma *et al.* (2001) reported that majority of soils of Himachal Pradesh were deficient in S. Tandon (2004) reported that about 37 per cent of Indian soils were low in available S.

2.1.3 Micronutrients

2.1.3.1 DTPA-extractable iron

Takkar and Nayyar (1981) observed Fe deficiencies in cultivated alluvial plains of Punjab. The high altitude soils of Sikkim had high available iron content and high organic matter content than the low altitude soils due to the acidic pH. An inverse relationship between availability of Fe and soil pH was found and irregular distribution in the soil solum (Jalali *et al.* 1989, Lahiri and Chakravarti 1989, and Mishra *et al.* 1990).

Tripathi *et al.* (1994) studied the distribution of micronutrients in the soils of Himachal Pradesh. They reported that available Fe varies from 15 to 41.2 mg kg⁻¹ in the soils of Solan district of Himachal Pradesh. Mahajan (2001) reported that the soils of Mandi district in Himachal Pradesh were high in DTPA extractable Fe (91 to 129 mg kg⁻¹).

Singh (2001) revealed that 12 per cent of the soils of India were deficient in available Fe. Amount of Fe varied from 3.3 to 205.0 mg kg⁻¹ in the soils of some mulberry gardens of Karnataka and its content decreased with soil depth (Samanta *et al.* 2002). Karki *et al.* (2005) reported low content of Fe (2.86 mg kg⁻¹) in high Himalayan region soils.

Sharma and Choudhary (2007) reported that available Fe content in the soils of lower Shivaliks of Solan district ranged from 8.2 to 50.2 mg kg⁻¹ and progressively declined with depth. Rattan *et al.* (2008) found that the contents of Fe in Indian soils varied from 3.4 to 68.1 mg kg⁻¹. Singh (2009) reported a deficiency of about 41 per cent in available Fe in soils of India. Chandel (2013) observed that the polyhouse soils of Mandi, Solan and Sirmaur districts had DTPA Fe ranging from 14.17 – 40.10, 13.38 – 43.36 and 13.67 – 47.20 mg kg⁻¹, respectively.

In general, Indian soils and specifically the hill soils were found to have sufficient to higher levels of available Fe at different locations.

2.1.3.2 DTPA-extractable manganese

Takkar and Nayyar (1981) observed Mn deficiencies in cultivated alluvial plains of Punjab. The content of available Mn of the high altitude soils of Sikkim was lower than that of low altitude soils. The high organic matter content in high altitude soils formed insoluble complexes with Mn and reduced its availability (Lahiri and Chakravarti 1989).

Tripathi *et al.* (1994) reported that average available Mn content in some soils of Himachal Pradesh was 29.0 mg kg⁻¹.

Mahajan (2001) reported that soils of Mandi district in Himachal Pradesh were high in DTPA extractable Mn (1.3 to 3.5 ppm), whereas, Singh (2001) revealed 5 per cent of Indian soils to be deficient in available Mn.

Nazif *et al.* (2006) have reported DTPA-extractable Mn to vary from 4.59 to 21.08 mg kg⁻¹ at different locations in Jammu and Kashmir soils. Sharma and Choudhary (2007) found that available Mn content in the profiles of lower Shiwalik hills of Solan district varied from 2.7 to 56.4 mg kg⁻¹ and the contents declined with the increase in profile depth.

Singh (2008) revealed that soils of seven states *viz.*, Bihar, Punjab, Haryana, Maharashtra, Madhya Pradesh, Tamil Nadu and Uttar Pradesh were deficient in available Mn

to the extent of 10.5 per cent. As regards Indian soils, deficiency of available Mn was to the extent of 1.9 per cent. In Himachal Pradesh, 5 per cent of the samples studied were deficient in available Mn.

DTPA-extractable Mn values varied from 5.01 to 23.85 mg kg⁻¹ in the soils under different land uses in Chambal ravines (Somasundaram *et al.* 2009). Sood *et al.* (2009) observed that the content of DTPA-Mn in the soils of Muktsar district of Punjab varied from 1.16 to 14.38 mg kg⁻¹. Singh (2009) reported 12 per cent deficiency of available Mn in soils of India.

Sharma and Kanwar (2011) reported that the total-Mn and DTPA-Mn varied from 27 to 216 mg kg⁻¹ and 1.3 to 22.3 mg kg⁻¹ with an average value of 104 and 6.5 mg kg⁻¹, respectively. Chandel (2013) observed that the polyhouse soils of Mandi, Solan and Sirmaur districts had DTPA Mn ranging from 1.14 – 17.84, 2.13 – 6.38 and 0.00 – 35.56 mg kg⁻¹, respectively.

The literature described above indicates that DTPA-extractable Mn status of the soil varied widely between deficient to sufficient range and decreased with soil depth.

2.1.3.3 DTPA-extractable copper

DTPA-extractable Cu varied from 1.28 to 4.88 mg kg⁻¹ in Sapruon valley of Solan district (Thakur and Bhandari, 1986). In the soils of Kashmir, available Cu content in high altitude soils ranged from 0.07 to 0.33 mg kg⁻¹. DTPA-extractable Cu was found to be high in surface horizons and decreased with the increasing depth of profile (Jalali *et al.* 1989). The low altitude soils of Sikkim were high in available Cu than the high altitude soils (Lahiri and Chakravarti, 1989).

Choudhary and Dass (1990) reported that calcareous soils of Bihar contained available Cu from 0.35 to 5.9 mg kg⁻¹. DTPA-extractable Cu did not follow any definite trend of distribution with profile depth in the soils of Haryana and Minicoy Island of Lakshdweep, (Sangwan and Singh 1993 and Vadivelu and Bandyopadhyay 1995).

Tripathi *et al.* (1994) reported that the content of DTPA-Cu ranged from 0.4-4.8 mg kg⁻¹ soil, with an average value of 1.7 mg kg⁻¹, in the soils of Himachal Pradesh. Mahajan (2001) found that the soils of Mandi district in Himachal Pradesh were high in Cu (1.7 to 2.8

mg kg⁻¹). Singh (2001) revealed that 3 per cent of the Indian soils were deficient in available Cu. Sharma *et al.* (2002) found that DTPA-extractable Cu ranged from 0.04 to 2.40 mg kg⁻¹ in soils of Punjab.

Available Cu content in the soils of lower Shiwaliks of Solan district ranged from 0.30 to 2.80 mg kg⁻¹ and it progressively decreased with depth (Sharma and Choudhary 2007).

Singh (2008) revealed that soils of seven states *viz.*, Bihar, Punjab, Haryana, Maharashtra, Madhya Pradesh, Tamil Nadu and Uttar Pradesh were deficient in available Cu to the extent of 3.6 per cent. In Himachal Pradesh; 27 per cent of the samples studied were deficient in available Cu.

Rattan *et al.* (2008) found that the contents of Cu in Indian soils varied from 0.2 to 5.0 mg kg⁻¹. Singh (2009) reported a deficiency of about 4 per cent of available Cu in soils of India. Talukdar *et al.* (2009) reported that under different land uses, DTPA-extractable Cu ranged from 0.35 to 6.05 mg kg⁻¹ with a mean value of 3.83 mg kg⁻¹, in rice soils of Golaghat district in Assam.

Sahoo *et al.* (2010) characterized the fertility status of agricultural lands of Manipur and found that available Cu was sufficient and ranged from 0.76 to 3.06 ppm. Shilpashree *et al.* (2011) revealed that soils of arecanut gardens in Karnataka were sufficient in Cu. Chandel (2013) observed that the polyhouse soils of Mandi, Solan and Sirmaur districts had DTPA Cu ranging from 1.04 – 7.44, 1.69 – 16.33 and 0.62 – 8.04 mg kg⁻¹, respectively.

2.1.3.4 DTPA-extractable zinc

Grewal *et al.* (1969) in an extensive study of soils of Himachal Pradesh, reported that available Zn status of Kullu valley soils was marginal and ranged from 0.38-0.60 mg kg⁻¹ and from 0.05-0.68 mg kg⁻¹, in surface and sub-surface soils, with mean values of 0.52 and 0.34 mg kg⁻¹, respectively.

Sakal *et al.* (1986) reported that the DTPA-extractable Zn in calcareous soils ranged from 0.34 to 3.42 ppm. DTPA-extractable Zn contents were found to vary from 0.56 to 6.76 mg kg⁻¹ in the temperate vegetable growing valley of Himachal Pradesh (Thakur and Bhandari, 1986). Further, Jalali *et al.* (1989) have reported that DTPA-extractable zinc varies

from 0.35 to 0.65 mg kg⁻¹, in the high altitude soils of Kashmir. They further reported that benchmark soils of Kashmir were deficient (0.15 to 1.00 mg kg⁻¹) in DTPA-extractable zinc.

Lahiri and Chakravarti (1989) reported lower contents of available Zn in the high altitude soils than the low altitude soils of Sikkim because of strong sorption of Zn by organic matter at high altitude soils.

Soils of Sirmour district were reported to be optimum in respect of all micronutrient elements, with available Zn ranging from 2.73-3.66 mg kg⁻¹, with a mean value of 2.99 ppm (Mamgain, 1990).

Tripathi *et al.* (1994) reported the distribution of micronutrients in the soils of Himachal Pradesh. The results show that available Zn varied from 0.1 to 2.8 mg kg⁻¹. The content of DTPA extractable Zn, by and large, decreased with depth and coincided with the distribution pattern of organic carbon in the profiles.

Mahajan (2001) reported that the soils of Mandi district in Himachal Pradesh are high in DTPA extractable Zn (5.5 to 8.3 mg kg⁻¹). Available Zn varied from 0.12 to 6.75 mg kg⁻¹ in soils of West Bengal under continuous cultivation of mulberry and its content decreased with depth (Samanta *et al.* 2002). Patil *et al.* (2003) found the available Zn content to vary from 0.29 to 3.25 mg/kg in soils in Konkan region of Maharashtra.

Sahoo *et al.* (2010) characterized the fertility status of agricultural lands of Manipur and found that available Zn was sufficient and ranged from 0.58 to 1.52 ppm. Chandel (2013) observed that the polyhouse soils of Mandi, Solan and Sirmaur districts had DTPA Zn ranging from 1.67 – 4.86, 1.63 – 4.52 and 0.98 – 4.75 mg kg⁻¹, respectively.

The literature clearly indicated a significant variation in available Zn content under different soils. In general, emerging trend in Zn deficiency has been reported by different workers across the country.

2.2 MACRO AND MICRONUTRIENT CONCENTRATION IN PLANTS

Soil analysis provides information about nutrient supply in soils, but the actual uptake can be monitored only by plant analysis. Since, leaf is the center of plant metabolism activity; therefore its analysis is of utmost importance in ascertaining the plant nutrient status.

2.2.1 Macronutrients

Chavan and Patil (1980) noted that there was lower level of leaf nitrogen (0.84%) in juvenile leaves of ber during June when they were one month old. A sudden increase (2.02%) in leaf nitrogen concentration was recorded during August, followed by a period of lower fluctuation up to December and sharp decline thereafter.

Prahlad Kumar and Pandey (1980) observed that there was decreasing trend of leaf nitrogen from March to May when leaves were 3 month old, followed by stable for June to July and continued to decrease thereafter in Guava.

Gururani and Singh (1983) observed that there was seasonal variation in the level of leaf nitrogen content in kinnow. Lesser amount of leaf nitrogen was recorded during summer (2.25%) and spring flushes (2.36%) as compared to those of autumn flush (2.4%).

Rehalia and Nijjar (1986) recorded highest level of leaf nitrogen in subtropical cv. Flordasun during March when leaves were one month old irrespective of their position.

Dhillon and Dhatt (1988) recorded an average of 2.84 per cent leaf nitrogen content in bearing kinnow under healthy condition. Bhargava and Rughupati (1993) reported that the optimum level of leaf nitrogen content in orange and lemon ranged from 2.2-3.8 per cent and 2.2-2.7 per cent respectively. However in case of Valencia orange the optimum range of leaf nitrogen content were reported between 2.4-2.6 by different workers (Reuther and Smith, 1955, Chapman, 1960 and Reuther *et al.*, 1962).

Singh *et al.* (1990) reported that there was higher leaf nitrogen content in acid lime in February flush as compared to those of June and September flushes. In case of lemon in most cases there was lower level of leaf nitrogen content during October and thereafter, showed an increasing trend until the maximum in early spring (Soni and Randhawa, 1974). Devrani and Sant Ram (1980) found lower level of leaf nitrogen in mango in March flush. In general leaf nitrogen concentration tend to decrease from November to July with the advancement of age, thereafter an increases trend was reported (Chadha *et al.*, 1980).

A seasonal fluctuation of leaf nitrogen concentration in Litchi has been reported by Sanyal and Mitra (1990). They found a gradual decrease of leaf nitrogen level from January to May, except in April and increasing tend thereafter until August, followed by a gradual decrease till December.

Randhawa and Kar (1967) noted that there was higher level of leaf P content at initial stage in all growth flushes in mandarin cvs Kaula and Nagpur. A gradual decline of leaf P content in both cvs with advancement of season was registered till February, just before the initiation of flushes. Higher concentration of leaf P was obtained in September flush followed by June and March flush respectively.

Randhawa and Kar (1967) while working on Nagpur and Kaula mandarin, observed that there was decreasing trend of leaf nitrogen content from May to August in both cultivars, followed by an increasing trend up to November and further starts to decline after December.

The optimum level of leaf phosphorus content in kinnow ranges from 0.12 to 0.16 per cent on dry weight basis. The plant is deficient when the range goes below 0.09 per cent (Anon, 1991). Empleton *et al.* (1971) found increasing yield of orange by increasing level of P upto 0.13 per cent on the basis of twelve -year experiment conducted in California. However, Bhargava and Raghupati (1993) have standardized foliar P standards for orange and lemon between 0.12 and 0.50 per cent and 0.1 to 0.3 respectively as a sufficient level under Indian agroclimatic condition.

Chadha *et al.* (1980) observed that there was decreasing trend of leaf P content in mango from November to July with the advancement of season, thereafter an increasing trend was registered.

A decreasing trend of leaf P content has been reported in acid lime with the advancement of season by Singh *et al.* (1990). Same trend of leaf P content in guava (Prahlad Kumar and Pandey, 1980) and custard apple (Dhandar and Bhargava (1993) has been reported with the advancement of season.

Gururani and Singh (1983), while studying macronutrient content of leaves from different growth flushes in kinnow, noted that there was decreasing trend of leaf K content during spring flush with the advancement of season. Same trend has been observed in summer flushing also except in 6 month of age while there was increased level of K (2.15%) than 4th and 5th month of age (1.96% and 1.88%) respectively. However, there was increasing trend of leaf K content during autumn flushes. The highest leaf K content was recorded during summer flushes (1.97%), medium (1.85%) and lowest (1.59) during spring flushes.

A decreasing trends of leaf K content with the advancement of season has been observed in acid lime (*Citrus aurantifolia*) as reported by Singh *et al.* (1990). Same trend of leaf K content with the advancement in season also has been reported in Guava (Prahlad Kumar and Pandey, 1980), custard apple (Dhandar and Bhargava, 1993), pomegranate (Bhargava and Dhandar, 1987) and mango (Chadha *et al.*, 1980). Chavan and Patil (1980) recorded highest (2.4%) level of leaf K content during June and gradual decline with the advancement of season except in August and reach minimum (0.9%) during January.

The optimum level of leaf K content in kinnow mandarin has been found 1.57 per cent on dry weight basis (Chahill *et al.*, 1991). The plant is deficient when the range goes below 0.72 per cent.

Randhawa and Kar (1967) noted that there was lower concentration of leaf calcium in mandarin at the initial stage of leaf in all growth flushes. With the advancement of season the level of leaf calcium content also increased and reach maximum during November and thereafter declined. But the extent of decline was not same among different flushes.

Chavan and Patil (1980) noted that there was gradual increase in the level of leaf Ca content in Ber with the advancement of season. The lowest leaf Ca (1.82%) was registered during June and highest (3.1%) in December.

Devrani and Sant Ram (1980), while studying the effect of age and flush on the mineral content of mango leaf, found that there was higher level of leaf calcium content during March flush (I) followed by July (II) and September (III) flushes. In general the leaf calcium has shown increasing trend for 6 months and were stable thereafter upto 12 months in first flush. There was no change in leaf calcium during II flush and highly fluctuating in III flush.

Gururani and Singh (1983) reported that the leaf calcium content of kinnow ranged from 2.73-3.68 per cent on dry weight basis depending upon type of growth flushes. The highest level of leaf calcium (3.68%) was recorded during spring flushes, lowest (2.73%) in summer flushes and moderate (3.21) during autumn flushes.

In case of Coorg mandarin the level of leaf calcium content in bearing terminal ranges from 3.18 to 5.25 per cent under varying agroclimatic condition and growth flushes in India (Anonymous, 1991). However in case of Nagpur mandarin the level of leaf calcium

content ranges between 1.32 to 1.55 per cent (Srivastava and Singh, 1998 and Srivastava and Kohli, 1997).

Increasing level of leaf calcium content also has been reported with the advancement of season in acid lime (*Citrus aurantifolia*) upto 140 days of leaf age and thereafter decline (Singh *et al.*, 1990).

Sanyal and Mitra (1990) found an indefinite pattern of leaf Ca content in litchi. The lowest level of leaf Ca content (0.33%) was recorded during February and highest 90.94% in December.

Increasing trend of leaf Ca also has been reported with the advancement of leaf age in custard apple (Dhandar and Bhargava, 1993), pomegranate (Bhargava and Dhandar, 1987) and guava (Prahlad Kumar and Pandey, 1980).

Chavan and Patil (1980) noted that the level of leaf Mg content in sapota was in the stability limits from May to August. It declined in September and October then steadily rise in November to December and attained highest in January.

The optimum level of leaf Mg in kinnow mandarin is 0.39 per cent on dry weight basis (Gururani and Singh, 1983). They noted that there was increasing trend of leaf Mg along with the advancement of season in spring and Autumn flushes, however, very little fluctuation has been registered during Summer flushing. Highest (0.43%) leaf Mg was reported in Autumn flushing and lowest (0.39%) during Spring and Summer.

Srivastava *et al.* (1994) while studying the seasonal trend of leaf Mg content in Nagpur mandarin, observed more or less irregular increasing trend of leaf Mg content till August, nearly constant from September to October and again irregular fluctuation thereafter.

2.2.2 Micronutrients

Reuther *et al.* (1962) stated that the optimum level of leaf Fe content in bearing mandarin ranges from 60 to 120 ppm. In case of kinnow, the optimum level of leaf Fe content was observed 103 ppm and deficient below 61 ppm (Chahill *et al.*, 1991).

Gururani and Singh (1983) observed an increasing trend of leaf Fe with advancement of season in spring flush of kinnow except 7 month of leaf age. However there was decreasing trend of this

element with the advancement of season during summer and Autumn. Spring cycle flushes were highest (69.10 ppm), summer flushes, moderate (67.35 ppm) and Autumn flushes were lowest (62.2 ppm) in average leaf Fe content.

Srivastava *et al.*, (1994) registered an increasing trend of leaf Fe content in Nagpur mandarin with the advancement of season from March (15.9 ppm) to August (57.9 ppm). Which is followed by a stable period from August to October (57.9 to 59.7 ppm) and increasing trend thereafter and attained highest (85.7 ppm) at the end of February.

Labanauskas *et al.* (1959) noted lower level of leaf Cu in Washington Navel orange during May. The element had an increasing trend after May and reached maximum during Septembers then tend to decline afterward and reached minimum in March.

The optimum level of Cu content in bearing mandarin ranged between 5-16 ppm (Reuther *et al.* 1962). In case of kinnow the optimum value of leaf Cu was 9.8 ppm (Chahill *et al.* 1991).

The Cu content in mango increased slowly along the advancement of season. The highest level of leaf Cu content attained in 5th (120 ppm), 7th (160 ppm) and 9th (160 ppm) month of leaf age on first (March), second (July) and third (September) flushes respectively (Devrani and Sant Ram, 1980).

The optimum level of Mn content in bearing mandarin ranged between 25-200 ppm (Reuther *et al.* 1962) and in kinnow, the optimum value of leaf Mn was 38 ppm on dry weight basis.

An increasing trend of manganese concentration had been observed in Washington Navel orange with the advancement of leaf age for a period from May to October. The concentration of Mn in leaves remained fairly stable from October to February. However, there could be slight decrease in leaf Mn concentration on March and April (Labanauskas *et al.* 1959).

In mango, Mn levels showed an increasing trend with age for 6 months and were stable thereafter upto 12 months in I flush. No seasonal fluctuation has been noted in leaf Mn content in the II and III flushes (Devrani and Sant Ram, 1980).

Young juvenile leaves of Ber has been found very rich in Mn content. From August onwards, the Mn content decline fairly consistently and reach minimum in January (Chavan and Paul, 1980).

Labanauskas *et al.* (1959) noted that there was higher level of leaf Zn content in Washington Navel orange in June (1 month old), July (2 month old) and September (4 month old). The concentration of Zn was nearly constant in July, August and September and tends to decrease with the age beginning from October to December.

The optimum level of leaf Zn content in bearing mandarin ranges from 25-100 ppm (Reuther *et al.* 1962). The bearing tree becomes deficient when the leaf concentration goes below 4.0-15.0 ppm (Chapman, 1960). But the non-bearing tree becomes deficient when leaf Zn goes below 18.0 ppm (Smith, 1966).

A lower concentration of zinc has been registered in sapota leaves in February, March and April, it raised up to May and June. There was a stable period from August to October. A lowest level of Zn has been registered in July and November (Chavan and Patil, 1980).

In Ber, the leaf Zn content has been found fairly stable from July to October. Besides this period there was large fluctuation in the level of Zn concentration (Chavan and Patil, 1980).

2.3 RELATIONSHIP OF SOIL PROPERTIES WITH NUTRIENT CONTENT IN SOILS

Soil fertility has been considered, in the past as a physico-chemical phenomenon taking place in the soil system. Soil characteristics and properties are the outcome of the interplay of pedogenic processes prevailing in an area and are very much needed for the interpretation of the soil fertility status. The interrelationships of soil nutrients with these properties decide the supplying power of respective nutrients by the soil. A review on interrelationships between soil properties and soil fertility is necessary for better production of nutrient supplying power of soils.

Soil pH

Soil pH is considered as the driver of soil fertility because of its direct impact on nutrient availability and plant growth. A pH range of 6 to 7 seems to promote the most ready

availability of nutrients. It is one of the properties that dictate the nutrient availability. Establishment of Hamlin orange trees in Florida flatwood soils showed no relationship between soil pH and tree canopy volume or orange yield in the soil pH range of 4.6–8.0. Below pH 4.6, tree size and yield reduced substantially due to toxic effect of Al^{3+} and H^+ ions (Obreza, 1973). Analysis of soil samples from old citrus orchards and from adjacent virgin soil in several districts of South Africa indicated no differential accumulation or depletion of any nutrient, and no pH soil change was observed in growing citrus for 20 years or more (Bredell and Conradie, 1975). The performance of Balady lime, Cleopatra mandarin, and Sour Orange seedlings evaluated at various soil pH values showed a reduction in growth by 9.8, 25.4, and 40.1% at soil pH 6.0, 7.0, and 8.0, respectively (Shawky *et al.* 1980).

Sakal (1986) reported that the DTPA-extractable Zn in calcareous soils ranged from 0.34 to 3.42 ppm. The soil available Zn was negatively correlated with pH ($r=-0.41^*$) and positively correlated with organic carbon ($r=0.71$). The Bray's per cent yield ranged from 29.12 to 126.36 and was positively correlated with available Zn ($r=0.93^{**}$) and plant tissue Zn ($r=0.91^{**}$).

Canopy of Satsuma mandarin at soil pH 4.0 was observed as half of trees growing at soil pH 5.0, and attributed low soil pH to heavy N fertilization (Yuda, 1985). Double acid extractable-Ca ($272-1249 \text{ mg kg}^{-1}$) and soil pH (5.8–6.2) under blighted trees were higher than Ca ($112-532 \text{ mg kg}^{-1}$) and pH (4.8–5.7) under healthy trees representing six major citrus belts of Florida, USA (Wutscher, 1989)

Katyal and Agarwala (1982) depicted an inverse relationship of soil pH with available micronutrient cations *viz.*, Fe, Mn, Zn and Cu. Mishra *et al* (1990) observed a positive relationship of soil pH with available P, Cu and Mn in foot hill soils of Himalayas. Rajkumar *et al.* (1990) reported that available Fe, Mn and Zn in hills and hill ridges of Bundelkhand were negatively correlated with soil pH.

According to Tiwary and Mishra (1990), available Zn and Mn were negatively correlated with pH; however, available Cu as well as Fe were positively correlated with pH. The pH values were found to increase with depth, possibly due to leaching of bases (Kaistha *et al.*, 1990; Sahu and Patnaik, 1990 and Walia and Rao, 1996).

The pH values of soils ranged from 4.3 to 9.9 in different regions of the country (Walia and Chamuah, 1990; Gangopadhyay *et al.* 1990; Verma *et al.* 1990; Sahu and Patnaik, 1990). Kaistha and Gupta (1993) reported that soil pH varied from 6.7 to 7.7 in the Central Himalayas of Himachal Pradesh, whereas, Singh *et al.* (1991) reported that it ranged from 6.5 to 8.4 in the mid altitude of outer Himalayas. However, the effect of copper (Cu) on the growth of Hamlin orange trees was more pronounced at soil pH range of 5.5–6.0 than at higher or lower soil pH regimes (Alva *et al.*, 1995). Walia and Rao (1996) reported that it ranged from 5.1 to 9.8 in the soils of North-Western Himalayas.

Gangopadhyay *et al.* (1998) found that paddy growing soils of Assam were moderately acidic at the surface (pH 4.7 to 5.7) and slightly acidic to nearly neutral in the sub-surface pH (5.0 to 6.8). Brady and Weil (2002) indicated that the solubility, availability and plant uptake of micronutrient cations (Cu, Fe, Mn and Zn) was more under acidic conditions (pH of 5.0 to 6.5).

Chaudhary *et al.* (2005) categorized soils of Himachal Pradesh as slightly acidic (pH 6.0) to mildly alkaline (pH 8.3) and values increased with depth which might be due to the decrease in organic carbon content.

The literature clearly indicates that soils of different cultivated lands are slightly acidic to moderately alkaline in reaction. pH increased with increasing soil depth and also show a differential correlation with other soil properties depending on the agro- climatic conditions of the region and crop species.

Electrical Conductivity (EC)

EC is a measure of soluble salt concentration in the soil solution. When a soil solution containing a relatively large amount of dissolved salts is brought into contact with a plant cell it causes shrinkage of the protoplasmic lining. This action, called plasmolysis increases with the concentration of the salt solution. Higher concentration of dissolved salts in any soil affects plant growth adversely. Increasing salt stress delayed fruit maturation, but had little effect on quality of Valencia orange (Cerdeira *et al.*, 1990; Dasberg *et al.*, 1991; Nieves *et al.*, 1991a; 1991b) and a slight increase in TSS and TSS/acid ratio in Shamouti orange (Bielorai *et al.*, 1988).

Arora and Takkar (1988) reported that available S showed a positive and significant relationship with EC in different soils. Singh and Choudhary (1990) observed a negative and non-significant relationship between available Cu and EC. Maas (1992) observed a decrease in Satsuma yield at the rate of 13% for each 1.0 dS m⁻¹ increase in EC of saturated soil extract beyond the threshold EC limit of 1.4 dS m⁻¹.

Ramana Murthy and Srivastava (1994) observed a positive and significant correlation of EC with available P, K and Fe in soils of lower Shivaliks. Available Cu had a positive and non-significant relation, while available Mn showed a negative and non-significant relation with it.

Chattopadhyay *et al.* (1996) revealed that micronutrients were significantly and negatively correlated with EC in the cultivated soils of hills and hill ridges of Rajasthan. Singh *et al.* (2005) found that EC varied from 0.16 to 0.35 dS m⁻¹ in surface and from 0.09 to 0.22 dS m⁻¹ in sub surface soils of Uttaranchal and decreased with increasing depth. Salinity is a critical issue in greenhouse water management of Mediterranean regions. The EC of the irrigation water in some coastal zones of Southern Italy is 1.6-3.2dS/m, whereas 40 per cent of the soils have an EC over 4 dS/m. Salinization may seriously compromise in soil physical-chemical properties (De Pascale *et al.*, 2003).

Trivedi *et al.* (2010) found a negative and highly significant relation of EC with available P in the soils of Madhya Pradesh. Bhanwaria *et al.* (2011) reported a negative and non-significant correlation between available micronutrients and EC in soils of Rajasthan.

Soil Organic Carbon

Soil organic carbon content is recognized as a key indicator of soil fertility and sustainability of agricultural systems. It has long been recognized as a source of plant nutrients, principally N and substantially P, S and micronutrients, besides being a promoter of a range of soil physical characteristics. According to Hodgson (1963), the presence of organic carbon may promote the availability of certain elements by supplying soluble complexing agents that interfere with their fixation.

Sauchelli (1969) reported a negative correlation between organic carbon and Cu as organic matter fixes Cu. Since Fe is held in the chelates as soluble complex there was a positive relation between organic carbon and Fe.

Bhandari and Randhawa (1985) observed a positive correlation of organic carbon with available micronutrient elements in soils of district Shimla. Ruhel and Paliwal (1980) found that available S had a significant correlation with organic carbon in the soils of Rajasthan.

The studies carried out by Singh and Datta (1988), Lahiri and Chakravarti (1989), Gangopadhyay *et al.* (1990) and Mandal *et al.* (1990) indicated an increase in organic carbon content with the increase in elevation. It was further observed that organic carbon content was high in the surface horizons which sharply decreased in the sub surface horizons of the profiles.

Kaistha *et al.* (1990) reported that organic carbon content varied from 0.3 to 8.3 per cent in the soils of different regions of Himachal Pradesh. Singh *et al.* (1991) reported moderately high content of organic carbon (1.40 to 2.58 per cent) in the mid altitude soils of outer Himalayas and the organic carbon content in the surface horizons of forest soils increased with increase in altitude (0.9 to 3.6 per cent).

Tripathi and Singh (1992) reported that sulphate sulphur and organic carbon shows a highly significant ($r=0.68^{**}$) correlation in the soils of Himachal Pradesh. The sulphate sulphur shows a significant decrease with increase in clay ($r=-0.44^{**}$) thereby, indicating greater retention of this form of sulphur by clay fraction in the soil. They also observed significant correlation between DTPA-Fe and organic carbon ($r=0.55^{**}$) which show that available Fe in soils is largely influenced by organic carbon content.

Garcia *et al.* (1994) reported that soil microbial population was less during periods when temperature and moisture conditions are low, while it peaked during rainy season when the litter decomposition rate is at its peak on the forest floor. Weak correlations were also obtained for the relationships between microbial C, N and P and soil physico-chemical properties. Microbial C, N and P all showed strong positive correlations with the soil moisture, soil temperature, air temperature, thickness of litter layer and light intensity in both gaps and understories. Soil properties such as clay content, WHC, pH, SOC and available-P also exerted a greater influence on microbial nutrients. Microbial biomass is usually negatively correlated with total soluble salt content.

Pikul and Aase (1994) found a significant correlation between bulk density and soil organic carbon in a silty loam soil. But, could not establish a relationship between organic

matter and physical properties of a silty loam soil. Kaistha and Gupta (1994) and Minhas *et al.* (1997) found the organic carbon content to decrease with decreasing with soil depth.

Kaistha and Gupta (1994) and Minhas *et al.* (1997) reported that organic carbon content decreased with increasing soil depth. The increase in organic carbon content with increase in altitude was due to continuous addition of leaf litter and slow decomposition of organic residues under low temperature. They further reported lower amounts of organic carbon in cultivated soils of Palampur (Kangra) and Ahju (Mandi) regions of Himachal Pradesh.

Sarkar and Sahoo (2000) found that organic carbon content of the soils varied from 0.08 to 0.86 per cent which decreased gradually with depth in Indo-Gangetic plains of Bihar.

Najar *et al.* (2009) found the organic carbon content in north facing pedons to vary from 0.16 to 3.5 per cent, whereas, in southern aspect it ranged from 0.1 to 2.4 per cent in the apple growing soils of Kashmir Valley. The organic carbon content in soils of dry temperate zone of Himachal Pradesh varied from 0.42 to 4.08 per cent (Sharma and Kanwar, 2010). Devi and Kumar (2010) found that the organic carbon content in the surface layer of the profiles of coffee growing soils of Karnataka ranged from 1.47 to 5.29 per cent and it decreased with depth.

The bulk density were found to be negatively correlated with soil organic matter (SOM) or SOC content (Weil and Magdoff 2004), loss of organic C from increased decomposition due to elevated temperatures may lead to increase in bulk density and hence making soil more prone to compaction via land management activities.

Wienhold *et al.* (2005) reported that to accomplish effective soil quality assessments, an understanding of the relationship between a soil indicator and a soil function is needed. Such relationships are needed to help managers in interpreting soils data. These relationships are necessary to determine if change in a soil indicator represents improvement or degradation of a soil function and to determine if differences in the value of an indicator between treatments over the time are meaningful.

The microbial biomass C, N and P in forest soil was expectedly higher as compared to other overburden areas. It is due to the fact that soil microbial biomass depends upon on soil

organic matter as substrate and therefore the decrease of soil organic C will cause the reduction of soil microbial biomass (Chen *et al.*, 2005).

Amacher *et al.* (2007) reported that more highly weathered soils tends to have lower organic carbon and nutrient contents and lower pH levels and higher acidity than soils in less intensively weathered regions of the country. Soil bulk density was influenced by soil organic matter levels because high amounts of lighter weight soil organic carbon resulted in lower bulk densities.

Manna *et al.* (2005) studied the effect of long-term fertilizer and manure on soil quality parameters of some soil groups of India. The results showed that application of NPK with FYM decreased soil bulk density in the surface (0–15 cm) soil over initial values whereas N, NP and NPK treatments increased it. Greater amount of C and N loss was observed under N and NP plots at Barrackpore and Ranchi whereas impact of these treatments was positive at Akola. Application of NPK or NPK + FYM had either maintained or improved C and N levels over initial soil status in all these systems.

2.4 RELATIONSHIP OF SOIL NUTRIENT CONTENTS WITH PLANT NUTRIENTS AND YIELD

Soil fertility is that component of productivity which primarily deals with nutrient supplying capacities of soil to the plant. Hence, the state of nutrition, size, and yield of citrus are closely related to the amount of soil explored by the root system (Avilan *et al.*, 1987). The occurrence of multi-nutrient constraints contributing to citrus decline like condition is widely reported. Consequently, the impact of nutrient management on improvement in orchard productivity is widely acclaimed (Ghosh and Singh, 1993; Zhou *et al.*, 1996; Li *et al.*, 1999; Srivastava and Singh, 2003; Srivastava and Singh, 2005).

Morphological symptoms of citrus decline in Sri Lanka as a symptom of a special chlorosis in form of appearance of silvery grey spots on upper surface of leaf in the areas having sandy soils, which resembled very much the symptoms of marble chlorosis induced by manganese Mn deficiency. These symptoms also resemble to those of zinc and iron deficiencies in Kinnow mandarin orchards of northwest India (Randhawa *et al.*, 1967). Some of the citrus growing soil types (Orthents and Psamments) in Valencia, Spain are so nicely managed that the fruit yield of $> 35 \text{ tons ha}^{-1}$ on an average is common even with limitation of sub-soil CaCO_3 as high as 37.8–39.9% and soil pH 7.9–8.1 (Hernando, 1969).

Soils maintaining exchangeable Ca and Mg collectively above 50–65% of CEC showed no response of Ca and Mg application in Valencia orange and rough lemon (Aso and Dantur, 1971). This is in contrast to other study (Quaggio *et al.*, 1992) which showed that maximum yield of Valencia orange on Rangpur lime rootstock was obtained at the soil exchangeable Mg level constituting more than 10% of total cation exchange capacity

Differences in soil fertility in sweet orange orchards of Agra region (India) revealed no significant difference between healthy and chlorotic trees. However, the leaf analysis values established Zn deficiency induced chlorosis due to antagonistic effect of Fe on Zn availability. Changes in cation-anion ratio and water soluble nutrients in soil were proposed to be promising approaches to explain citrus blight syndrome (Wutscher and Hardesty, 1981).

Aso and Bustos (1981) based on different citrus regions of Argentina reported the appearance of hidden signs of Mg deficiency on soils having exchangeable Mg^{+2} less than 0.8 m.e. 100 g^{-1} . Hidden hunger signs are also produced due to high K ($K/Mg > 4.0$) or Ca ($Ca/Mg > 7$) content. Comparative studies made on the soil conditions in a young sweet orange orchard with patches of poor growth and in adjacent areas with normal growth revealed that soil conditions in the affected areas had the presence of higher total soluble salts, higher concentration of soluble and exchangeable sodium, and lower soluble calcium and magnesium (Milad *et al.*, 1975; Malewar *et al.*, 1983). Deep tillage has met with mixed success as a method of ameliorating subsoil, a physical limitation to root growth. In many cases, benefits are transient and variable (Eck and Unger, 1985). This in large parts stems from not understanding the basic factors influencing the effectiveness of the modification and the subsequent maintenance of structural stability. Poor growth of Nagpur mandarin in central India (Nilangekar and Patil, 1982) was attributed to presence of high clay, silt, $CaCO_3$ in subsoil. For subsoil appraisal, Shishov and Kapshuk (1984) suggested that reddish brown soils of the Tripolitanian coastal plain of USSR are considered suitable for Citriculture, if the following criteria are met: soil depth more than or up to 60 cm, $CaCO_3$ less than or up to 8–12%, EC less than or up to 5.0 mmhos cm^{-1} , and gypsum less than or up to 30%.

The average concentration of clay fraction increased from 31 to 38% as the elevation increased from 850 to 1500 m above mean sea level (Kong-Tau, 1986). Likewise, many of the soil fertility parameters are reported to be influenced by variation in altitude (Singh and Dutta, 1983; Avasthe and Avasthe, 1995). Other studies with reference to highest fruit yield of Satsuma mandarin ($10\text{--}12\text{ tons ha}^{-1}$) suggested the values in soil as: $31\text{--}49\text{ mg } 100\text{ g}^{-1}$

exchangeable K, 52–54 mg 100 g⁻¹ Mg, and 197–223 mg 100 g⁻¹ Ca with Ca: Mg 2.5–3.0, Mg: K₂O 3.0–4.0, and Ca: K₂O 8.0–10.0 in Western Georgia (Beridze, 1987). Ko and Kim (1987) observed that high yielding orchards had high mineral content, but low in available P. Available N and K levels were high in those orchards practicing cultivation of mid-season cultivars in Jeju county of Korea with average values of soils as pH 5.7, organic matter 8.9%, and exchangeable K, Ca, Mg, and N levels of 1.4, 6.7, 2.3, and 0.2 me 100 g⁻¹ soil, respectively.

These observations assume a greater significance considering the fact that citrus culture for commercial purposes is being practiced up to an altitude as high as 2400 m above mean sea level (Ding *et al.*, 1990). The central element for optimization of soil properties is the optimum value, best regarded not as a constant, but having a range of values associated with highest crop yield. The idea has become firmly established that the optimum value is rather a variable quantity, but the current models of soil fertility take little or no notice of this fact (Medvedev, 1990). Larson and Pierce (1991) suggested that minimum data set consisting of soil attributes namely, nutrient availability index, total organic carbon, labile organic carbon, particle size, plant available water content, soil structure, soil strength, rooting depth, pH, and electrical conductivity must be considered for suitability appraisal.

Analysis on contribution of climate, soil, and management factors on yield of Satsuma mandarin demonstrated that yield is more affected by physiographic environment than either climate or even fertilizer application (Egashira *et al.*, 1990). A definite correlation exists between elevation and particle size composition of soils. Comparison of soil properties under etiolated versus normal citrus trees showed a significantly higher pH, exchangeable Ca²⁺, and Mg²⁺ (7.7, 146.1 mg kg⁻¹, and 110.9 mg kg⁻¹) under etiolated trees than the corresponding values (5.3, 514.1 mg kg⁻¹, and 82.9 mg kg⁻¹) of the soils under normal trees (Cheng and Zeng, 1991). It is often observed a kind of secondary transformation of decline-like symptoms. In such cases, nutrient constraint may not be necessarily involved. Higher K associated lower concentration of Fe, Mn, and Zn is common in the rhizosphere soil of blighted trees than those of healthy trees (Pavan and Wutscher, 1993).

Evaluation of various citrus growing soil series for citrus production in central Taiwan revealed the suitability of 27 soil series and 5 great groups. Orchards established on dark grey colluvial soils registered the highest fruit yield of 28.1 tons ha⁻¹ and lowest yield of 16.1 tons ha⁻¹ on yellow soils. In terms of soil series, the highest fruit yield of 39.6 tons ha⁻¹ and 16.1

tons ha⁻¹ was observed on grey yellow colluvial and yellow earth colluvial soils, respectively (Lay and Wang, 1997).

Mean exchangeable-Ca²⁺ was observed to be higher (33.8 mg 100 g⁻¹) under healthy trees compared to declining Nagpur mandarin trees (29.2mg 100 g⁻¹) established on Entisols, Inceptisols, and Vertisols. The nutrient mining-linked fertility depletion in surface (Srivastava and Singh, 2004a) and sub-surface soil (Dass *et al.*, 1998; Reddy *et al.*, 2003) is by and large responsible for citrus decline in Deccan plateau of India

Nunez- Moren and Valdez-Gascon (1994) observed average values of different soil properties as: 1.1 dS m⁻¹ ECe, 6 me L⁻¹ water soluble Na, 4 me L⁻¹ Ca, 1.2 me L⁻¹ Mg, and exchangeable sodium percentage 4.6 me L⁻¹ for the orchards having high productivity of 162 kg per tree. These values were different at lower productivity level of 48 kg per tree as: 3.8 dS m⁻¹ ECe, 12 me L⁻¹ water soluble Na, 16 me L⁻¹ Ca, 3.8 me L⁻¹ Mg, and 7.3 me L⁻¹ exchangeable sodium percentage.

Attempting to ameliorate a physical problem without correcting an underlying chemical cause is a common mistake. An example is the failure of deep ripping of subsoil without ameliorating sodicity (Rengaswamy *et al.*, 1992). The citrus yield was not correlated with a single soil nutrient content, but was correlated with Mg/K and Ca+Mg/K ratios in the fertilized rows of the low productivity orchards only . Quaggio (1998) showed that excess of K fertilization decreased citrus yield in the State of São Paulo.

For the low productivity orchards it is possible that the normal yearly application of mineral fertilization (N, P and K) associated with low lime frequency increased leaching of basic cations in the fertilized rows, specially Mg (Fidalski and Auler, 1997). The results of this citrus nutritional survey showed nutritional problems associated with Ca, Mg and Zn in the low productivity orchards. Similar results have been reported for the citrus orchards in the Northwestern part of Paraná (Fidalski and Auler, 1997).

Kohli *et al.* (1997) reported a significant correlation of leaf N , P, Fe, Mn and Zn with fruit yield The fruit yield was better correlated with soil available Ca + Mg than leaf Ca and /or Mg content. These observations indicated leaf analysis, a better tool to identify the nutritional problems. While for Mg nutrition, soil analysis proved better than leaf analysis.

The studies in the past have shown the better reliability of leaf than soil analysis for diagnosing the nutrient constraints of citrus orchards.

For the Northwestern region of Paraná, it has been found that Ca nutrition increased citrus yield in soils originated from *Caiuá* geological formation (Fidalski *et al.*, 1999a). It is also possible that Ca and Mg uptake by plants may be reduced due to the high concentration of soil K in the fertilized rows. This hypothesis is supported due to the strong antagonism among these three cations (Ca, Mg and K) observed in the soils for Fidalski *et al.* (1999a, b). Relationship analysis showed that the fruit weight was positively related with leaf Zn in the low productivity orchards, while in the high productivity orchards the fruit weight was positively related with leaf Ca and soil Ca in the fertilized rows. The fruit weight did not correlate with leaf K of low and high productivity orchards. The high K in the fertilized rows and leaf Zn deficiency in the low productivity orchards, were assumed to be the main nutritional factor in reducing fruit size. This is supported by the works published by Malavolta & Violante Netto (1989), Quaggio (1996), Fidalski & Auler (1997), and Fidalski *et al.*, (1999a, b).

The citrus soils differ from other cultivated soils in many respects. The cultivated soils remain fallow for 3–6 months every year, which results in depletion of soil organic matter as very little carbon (C) is added during the fallow phase, while biological oxidation of existing C continues at the same rate as in citrus soils (Sharma and Singh, 2001). Many investigations enumerated the decline of citrus trees to unfavorable surface and subsurface soil conditions (Wutscher, 1989; Srivastava and Singh, 2004a). Of late, multi-micronutrient deficiency in Marathwada region of Maharashtra, India was established to be the causal factor for sweet orange decline (Srivastava and Singh, 2004a).

Chapter-3

MATERIALS AND METHODS

The precision of experimentation and its scientific validation depends on the methodology adopted. The relative importance of soil quality attributes varies among different soils in various agro-ecological conditions and therefore, site specific information is needed for evaluation of soil fertility. This chapter presents the analytical tools /methods employed to achieve the specific objectives under the following heads:

3.1 General description of the study area

3.2 Survey of mango orchards

3.3 Soil and plant analysis

3.4 Interpretation of data

3.5 Statistical analysis

3.1 General description of the study area

The district lies between 77° 01' 12" and 77° 49' 40" East longitude and 30° 22' 30" and 30° 01' 20" North latitude and occupies an area of 2,825 square kilometer which is almost 5.07 per cent of the total geographical area of the state. Area wise it is the fifth smallest district of the state. It is encapsulated in the north by Shimla, in the south by Yamuna Nagar district of Haryana, in the east by Uttar Pradesh and in the North-West by Solan district. The district presents an intricate mosaic of high mountain ranges, hills and valleys with altitude ranging from 300 to 3000m above MSL. The river Giri is the biggest river in the district which originates from Kotkhai/Jubbal tehsil of Shimla district and flows down in the south-west direction. It ultimately joins the river Yamuna near Paonta Sahib. Another important river which forms the eastern border of the Sirmour district is the river Tons.

3.1.2 Climate

The district has sub-humid, sub-tropical, humid subtropical and humid temperate climate zones. The mean annual temperature ranges from 10°-24°C and the mean annual precipitation is approximately 1405 mm major part of which is received during the months

of July to September. Mean maximum and minimum temperature of 30°C and 0°C respectively.

3.1.3 Soil type

The soil in the district varies from thin and bare soil of high mountains to rich deep alluvial soil of the valleys. The texture of soil ranges from loamy sand, sandy loam and loam to sandy clay loam. Colour of the soil varies from brown to dark brown. The soil is acidic in nature at higher reaches and near neutral in the valleys and plains

3.2 SURVEY OF MANGO ORCHARDS

A preliminary survey of the study area was conducted in order to select and collect basic information on the soil, water, nutrient management and other cultural practices being followed in the orchards. The survey revealed that Nahan and Paonta Sahib blocks are the major centers of commercial mango production, hence the studies were restricted to these two blocks. Based on uniformity in respect of age and tree vigour, 40 representative mango orchards in blocks of Sirmour district were selected. “Dashehri” variety of mango was selected for study.

3.3 SOIL AND PLANT ANALYSIS

3.3.1 Collection and preparation of soil samples

Composite soil samples were drawn from the basin of 10 trees from two depths i.e. 0-15 and 15-30 cm in each selected orchard in the month of October/November, prior to the application of fertilizers by the farmers. The soil samples were drawn from the basins of those trees from which leaf samples were also collected. Collected soil samples were air dried in shade and ground with the help of pestle mortar. These ground samples were then passed through 2 mm sieve and stored in polyethylene bags for further analysis.

3.3.2 Collection and preparation of leaf samples

Representative leaf samples comprising of 25-30 leaves (latest mature flush from middle of terminal growth) were collected from 10 randomly selected trees of the Dashehri variety in each orchard from which soil samples will also be taken. The leaf samples were washed with tap water and then with 0.1N HCl and finally with double distilled water. The samples were spread on filter paper for air drying and were subsequently put in paper bags,

which were kept in hot air oven at $60 \pm 5^{\circ}\text{C}$ for 48 hours for drying. The dried samples were crushed, ground and stored in butter paper bags for the estimation of N, P, K, Mg, Cu, Fe, Mn and Zn contents (Chapman , 1964).



3.3.3 Soil analysis method

The soil samples were further analyzed for pH, electrical conductivity (EC), organic carbon (OC), available macro and micronutrient (N, P, K, Ca, Mg, S, Mn, Fe, Zn, Cu) using standard methods as given below.

a) Soil pH

Soil pH was measured by digital pH meter by mixing soil and water in the ratio of 1:2.5.

b) Electrical Conductivity

Electrical conductivity of the soil was measured in soil: water suspension (1:2) at 25⁰ with digital microprocessor based conductivity meter.

c) Organic Carbon

It was measured by employing the method given by Walkley and Black (1934):

Soil organic matter (%) = Organic carbon (%) x 1.732

Organic carbon (%) was determined by titration method and measured as:

Organic carbon (%) = [Blank value – Titrated value] x 0.195

d) Available macronutrient elements

Available N was determined by alkaline potassium permanganate method of Subbiah and Asija (1956). Available P was extracted by using 0.5 M sodium bicarbonate (NaHCO₃) at pH 8.5 (Olsen *et al.*, 1954) and determined by SnCl₂ reduced ammonium molybdate blue colour method (Jackson, 1957). Available K was extracted by neutral normal ammonium acetate (Merwin and Peach, 1951) and determined by flame photometer. Exchangeable Ca and Mg in the ammonium acetate extract were determined by atomic absorption spectrophotometer (Sharma *et al.*, 1987). SO₄²⁻-S was extracted by Morgan's reagent (Morgan, 1937) and determined by turbidity method of Chesnin and Yien (1950).

e) Available micronutrient elements (cations)

Available Fe, Mn, Cu and Zn contents in soil were extracted by using DTPA extract at pH 7.3 (Lindsay and Norvell, 1978) and determined on atomic absorption spectrophotometer.

3.3.4 Plant Analysis

Digestion of leaf samples

Well ground samples of known weight of leaf were digested in di-acid mixture prepared by mixing concentrated HNO₃ and HClO₄ in the ratio of 4:1 observing all relevant precautions and making the final volume to 100 ml (Piper,1966) for estimating P, K, Mg, Cu, Fe, Mn, Zn contents. Separate digestion was carried out for nitrogen (N) estimation using concentrated H₂SO₄ and digestion mixture (Potassium sulphate 400 parts, copper sulphate 20

parts, mercuric oxide 3 parts and selenium powder 1 part) as suggested by Jackson (1973). Nutrients were estimated following the methods given in Table 3.1

Analysis of digested samples

The total N was analyzed by the micro- Kjeldahl's method as outlined in A.O.A.C (1970). Phosphorus in the di-acid digest was determined by vanado- molybdate yellow colour method (Jackson, 1973). Potassium and calcium in the digest were determined on flame photometer (Jackson, 1967). Sulphur was determined by turbidimetric method as outlined by Chesnin and Yien (1950). Iron, manganese, copper and zinc were determined on atomic absorption spectrophotometer (Vogel, 1978).

Table 3.1: Methods followed for the analysis of soil and plant samples

Parameter		Method and reference
1.	pH	1:2.5 Soil : water suspension, measured with digital pH meter (Jackson, 2005)
2.	EC	1:2.5 Soil : water suspension, measured with digital EC meter (Jackson, 2005)
3.	Organic carbon	Walkley and Black wet digestion method (Walkley and Black, 1934)
4.	Available N	Alkaline potassium permanganate method (Subbiah and Asija, 1956)
5.	Available P	Olsen's method (Olsen <i>et al.</i> , 1954)
6.	Available K	Ammonium acetate method (Merwin and Peach, 1951)
7.	Available Ca	Ammonium acetate method (Merwin and Peach, 1951)
8.	Available Mg	Ammonium acetate method (Merwin and Peach, 1951)
9.	SO ₄ ²⁻ - S	0.15% CaCl ₂ extractant and turbidimetric determination (Chesnin and Yien, 1950)
10.	Cu	DTPA extractant(Lindsay and Norvell,1978)
11.	Fe	DTPA extractant(Lindsay and Norvell,1978)
12.	Mn	DTPA extractant(Lindsay and Norvell,1978)
13.	Zn	DTPA extractant(Lindsay and Norvell,1978)
Leaf analysis		
1.	N	Micro-kjeldhal method (Jackson, 1973)
2.	P	Vanado-molybdate phosphoric yellow color method (Jackson, 1973)
3.	K	Flame photometer method (Jackson, 1973)
4.	Mg	Atomic absorption spectrophotometer (Sarma <i>et al.</i> ,1987)
5.	Cu	Atomic absorption spectrophotometer (Sarma <i>et al.</i> ,1987)
6.	Fe	Atomic absorption spectrophotometer (Sarma <i>et al.</i> ,1987)
7.	Mn	Atomic absorption spectrophotometer (Sarma <i>et al.</i> ,1987)
8.	Zn	Atomic absorption spectrophotometer (Sarma <i>et al.</i> ,1987)

3.4 INTERPRETATION OF DATA

Results of soil analysis were interpreted by using the critical limits given in the tables 3.2, 3.3 and 3.4 and plant analysis results were interpreted using tables 3.5.

Table 3.2 Critical limits used for interpretation of soil pH and Electrical Conductivity

pH	
Below 6.5	Acidic
6.5-7.5	Normal
Above 7.5	Alkaline
Electrical Conductivity(dSm⁻¹)	
Below 0.8	Normal- Suitable for all crops
0.8-1.6	Critical for salt sensitive crops
1.6-2.5	Critical for salt tolerant crops
Above 2.5	Injurious to all crops

Table 3.3 Critical limits used for interpretation of Organic carbon and primary macronutrients

Sr. No.	Nutrient Element	Soil Fertility Class			References
		Low	Medium	High	
1.	Organic Carbon (%)	<0.5	0.5-1.5	>1.5	Bhandari and Tripathi(1979)
2.	Available N (kg ha ⁻¹)	<280.0	280.0-560.0	>560.0	FAI (1977)
3.	Available P (kg ha ⁻¹)	<10.0	10.0-24.6	>24.6	FAI (1977)
4.	Available K (kg ha ⁻¹)	<98.6	98.6-280.0	>280.0	FAI (1977)
5.	Available Ca [cmol (p ⁺) kg ⁻¹]	<1.5	-	>1.5	Tandon (1989)
6.	Available Mg [cmol (p ⁺) kg ⁻¹]	<1.0	-	>1.0	Tandon (1989)
7.	Available S (mg kg ⁻¹)	<10.0		>10.0	Tandon (1989)

Table 3.4 Critical limits for interpretation of available micronutrients

Sr. No.	Micronutrients (mg/kg)	Availability					References
		Very low	low	medium	high	Very high	
1.	Zn	<0.5	0.5- 1.0	1.0-3.0	3.0- 5.0	>5.0	Lindsay and Norvell, 1978
2.	Cu	<0.1	0.1-0.3	0.3-0.8	0.8- 3.0	>3.0	
3.	Fe	<2.0	2.0-4.0	4.0- 6.0	6.0-10.0	>10.0	
4.	Mn	<0.5	0.5-1.2	1.2- 3.5	3.5-6.0	>6.0	

Table. 3.5 Critical limits of nutrients for plant samples

Sr No.	Nutrient Element	Concentration			References
		Low	Medium	High	
A.(per cent)	Macro nutrients				Tandon,1989
1.	N	0.70-0.99	1.00-1.50	>1.50	
2.	P	0.05-0.07	0.08-0.25	>0.25	
3.	K	0.25-0.39	0.40-0.90	>0.90	
4.	Ca	1.00-1.99	2.00-5.00	>5.00	
5.	Mg	0.15-0.19	0.20-0.50	>0.50	
6.	S	0.15-0.20	0.20-0.40	>0.40	
B.(ppm)	Micro nutrients				
7.	Cu	5-6	7-50	>50	
8.	Zn	15-19	20-200	>200	
9.	Fe	25-49	50-250	>250	
10.	Mn	25-49	50-250	>250	

3.5 STATISTICAL ANALYSIS

The descriptive statistics viz., range, mean, standard error and coefficient of variation were derived for each soil (0-15 and 15-30 cm) and leaf parameters. The data was subjected to statistical analysis by adopting simple correlations to find out the extent of relationship between soil and leaf nutrient status and the relationship of soil properties with nutrient contents. The descriptive analysis was done by data analysis function of MS Excel 2007 and correlation analysis was done by using SPSS v16.0 (IBM Corp. Released 2007).

Chapter-4

RESULTS AND DISCUSSION

Soil chemists judge a soil's nutrient status by estimating the "plant available" fraction of the total nutrients present in it, by using established methods which must be accurate, precise and rapid. Based on the estimated available nutrient status, the soils are then divided into low, medium or high classes. It is accepted that the soils testing low or medium cannot support medium or high crop yields on their own and require fertilizer application. Lower the soil's fertility (greater the nutrient deficiencies), higher will be the rate of nutrient application to meet the crop needs. Fertility of soils is a result of presence of essential plant nutrients in adequate amounts and in available forms to the plant. The work on soil fertility should be a continuous one so that changes in fertility status of soils can be assessed periodically for making more scientific recommendations on soil fertility management.

In the light of the above stated facts, the present investigation entitled "**Soil and plant nutrient contents in mango orchards of Sirmour districts of Himachal Pradesh**" was undertaken and its results are presented below under the following heads:

4.1 Soil fertility status

4.1.1 Chemical properties of the soils

4.1.2 Macronutrient status of the soils

4.1.3 Micronutrient status of the soils

4.2 Nutrient indices of soil

4.3 Nutrient concentration in the leaves of mango

4.4 Relationship of soil properties with nutrient content in soils

4.5 Relationship of soil properties and nutrient contents with plant nutrients

4.1 SOIL FERTILITY STATUS

4.1.1 Chemical properties of the soils

4.1.1.1 Soil pH

In Nahan block the soil pH in the surface 0-15 cm layer ranged from 6.47 to 7.42 with the mean value of 7.02. In the sub-surface 15-30 cm layers, the values ranged were 6.76 to

7.52 with mean value of 7.10, respectively (table 4.1). In Paonta Sahib block the values ranged from 6.84 – 7.38 and 6.95 – 7.65 with mean values of 7.11 and 7.26, for the surface and sub-surface soil depths, respectively. The coefficient of variation of 8.27 and 6.59 per cent for Nahan block and 8.85 and 6.13 per cent for Paonta Sahib block indicates that, it varied spatially in the surface and sub-surface depths, respectively.

The pH values were found to increase with depth, possibly due to leaching of bases (Kaistha *et al.* 1990, Sahu and Patnaik 1990 and Walia and Rao 1996). Sarkar and Sahoo (2000) and Patil *et al.* (2008) also found that the pH value increased with depth as soil alkalinity increases with depth due to deposition of basic salts by irrigation and elluviation.

The soils of the study area were found to be near neutral in reaction which corroborate the findings of Kaistha and Gupta (1993) who also observed similar trends in Central Himalayas of Himachal Pradesh. Minhas *et al.* (1997) concluded that these soils were less acidic because of their location at relatively lower altitude and also lower amount of organic carbon in the surface horizon.

4.1.1.2 Electrical conductivity (EC)

The electrical conductivity in the surface (0-15 cm) soils in the mango orchards of Nahan block ranged from 0.25 - 0.68 dS m⁻¹ with the mean value of 0.50 dS m⁻¹ and in the sub-surface (15-30 cm) layer value ranged from 0.21-0.54 dS m⁻¹ with a mean value of 0.40 dS m⁻¹ (table 4.1). The respective values for soils of Paonta Sahib block were 0.27 – 0.67 and 0.23 – 0.52 dS m⁻¹ with mean value of 0.47 and 0.37 dS m⁻¹ in the surface and sub-surface depths, respectively. The coefficient of variation for EC indicates that salt content in both the depths varied spatially. In the sub- surface (15-30 cm) layer the electrical conductivity was found to decrease which has also been reported by Sharma (1994), Singh *et al.* (2005), and Kumari (2015). Since, the EC value <0.8 dS m⁻¹ is normal and suitable for all crops (Richards, 1954), the soils of mango orchards of the district were in safe limits. These soils are free from soluble salts, hence, responsive to fertilizer application.

4.1.1.3 Organic carbon (OC)

Organic carbon is the key component of soil because of its influence on physical, chemical properties and soil biota. A perusal of the data depicted in table 4.1 shows that the organic carbon content in the surface 0-15 cm layer of Nahan block ranged from 12.56 to 21.85 g kg⁻¹ with mean value of 17.51 g kg⁻¹, whereas, in the sub-surface layer it ranged

Table. 4.1 Soil pH, EC and organic carbon contents in the mango orchards of Sirmour district

NAHAN BLOCK							PAONTA SAHIB BLOCK						
Orchard No.	Soil pH		Electrical conductivity (ds m ⁻¹)		Organic carbon (g kg ⁻¹)		Orchard No.	Soil pH		Electrical conductivity (ds m ⁻¹)		Organic carbon (g kg ⁻¹)	
	Soil Depth (cm)							Soil Depth (cm)					
	0-15	15-30	0-15	15-30	0-15	15-30		0-15	15-30	0-15	15-30	0-15	15-30
1	7.42	7.08	0.54	0.46	15.35	13.25	1	7.01	7.21	0.57	0.46	14.54	12.56
2	6.89	6.76	0.45	0.36	16.5	14.65	2	7.26	7.36	0.55	0.38	18.58	16.75
3	7.24	7.02	0.42	0.32	12.56	10.45	3	7.02	7.12	0.47	0.36	19.75	17.15
4	6.78	6.95	0.34	0.27	15.4	13.65	4	7.25	7.32	0.38	0.31	19.85	16.95
5	7.02	7.08	0.65	0.48	18.65	16.85	5	7.58	7.65	0.28	0.23	16.25	13.45
6	6.93	7.05	0.25	0.21	16.65	11.25	6	7.11	7.24	0.57	0.37	18.36	16.60
7	7.41	7.52	0.68	0.54	21.55	19.05	7	6.93	7.15	0.41	0.33	12.65	10.75
8	7.08	7.09	0.64	0.47	19.85	17.35	8	7.04	7.21	0.47	0.34	13.35	11.65
9	7.11	7.26	0.32	0.25	18.95	16.76	9	6.88	6.99	0.31	0.24	20.45	19.85
10	6.97	7.04	0.51	0.43	16.75	14.25	10	7.08	7.21	0.67	0.52	19.25	16.45
11	7.37	7.42	0.51	0.45	16.65	14.75	11	7.22	7.36	0.29	0.25	22.75	21.15
12	7.06	7.12	0.52	0.42	18.75	14.85	12	6.90	7.06	0.41	0.34	18.95	16.75
13	6.88	7.07	0.49	0.34	14.25	12.95	13	6.84	6.95	0.56	0.42	20.54	18.65
14	7.22	7.34	0.58	0.46	15.45	13.25	14	7.14	7.46	0.43	0.35	19.45	17.35
15	7.18	7.25	0.66	0.48	19.95	16.75	15	7.19	7.28	0.53	0.44	21.65	20.05
16	6.93	7.08	0.53	0.42	21.85	19.80	16	7.07	7.14	0.62	0.47	21.25	20.50
17	6.47	6.98	0.65	0.47	14.75	12.6	17	7.17	7.26	0.27	0.23	18.75	16.70
18	6.67	6.85	0.54	0.45	19.65	17.85	18	7.11	7.36	0.64	0.48	16.50	14.20
19	7.02	7.16	0.47	0.39	19.45	17.5	19	7.30	7.43	0.47	0.36	21.85	19.55
20	6.82	6.91	0.34	0.26	17.25	15.75	20	7.17	7.39	0.55	0.46	22.35	20.65
Range	6.47-7.42	6.76-7.52	0.25-0.68	0.21-0.54	12.56-21.85	10.45-19.80	Range	6.84-7.58	6.95-7.65	0.27-0.67	0.23-0.52	12.65-22.35	10.75-21.15
Mean	7.02	7.10	0.50	0.40	17.51	15.18	Mean	7.11	7.26	0.47	0.37	18.85	16.89
C.V (%)	8.27	6.59	24.46	23.34	14.30	16.72	C.V(%)	8.85	6.13	26.00	23.90	15.28	18.72

from 10.45 to 19.80 g kg⁻¹ with mean value of 15.18 g kg⁻¹. The respective values for Paonta Sahib block were 12.65-22.35 and 10.75-21.15 g kg⁻¹ with the mean value of 18.85 and 16.89 g kg⁻¹ in the surface and sub-surface depths, respectively. The coefficient of variation of 14.30 and 16.72 per cent for Nahan block, while 15.28 and 18.72 per cent for Paonta Sahib block indicates that, it varied spatially in the surface and sub-surface depths, respectively. The organic carbon was found to decrease with increase in soil depth. The overall status shows that the soils were medium to high in organic carbon with 15 and 85 per cent samples in medium and high categories, respectively, in both the blocks. This may be due to the management practices and variable addition of FYM.

Lesser amount of organic carbon is found in more hotter and dry areas. Variable distribution and land management practices can result in decrease in soil organic matter levels. Minhas *et al.* (1997) reported that the cultivated soils of Kangra district of Himachal Pradesh contained lower amounts of organic carbon, as compared to other regions of the state. The results obtained are in accordance with the findings of Kumar *et al.* (2012) who reported that organic carbon contents in most of the soil samples were low in mango orchards of district Uttar Pradesh, but several workers in Himachal Pradesh have reported a high organic carbon content in fruit growing soils, in general.

4.1.2 Macronutrient status of soil

4.1.2.1 Available nitrogen (N)

The data depicted in table 4.2 revealed that the available nitrogen in the surface (0 to 15 cm) soils of Nahan block varied from 324.78 - 412.76 kg ha⁻¹ with a mean value of 376.19 kg ha⁻¹, whereas, in the sub-surface (15-30 cm) soils it varied from 309.54 - 393.87 kg ha⁻¹ with an average value of 357.60 kg ha⁻¹. The respective values for Paonta Sahib block were 319.48 - 416.96 kg ha⁻¹ and 288.79 - 396.41 kg ha⁻¹ with mean values of 372.01 and 353.53 kg ha⁻¹ for surface and sub-surface soils, respectively. The coefficient of variation of 5.82 and 6.30 per cent for available N of Nahan block and 7.31 and 7.96 per cent for Paonta Sahib block indicates that, it varied spatially in the surface and sub-surface depths, respectively. The distribution of available nitrogen exhibited a decreasing trend with the increase in soil depth. The values were subsequently categorised into different levels of soil fertility (table 4.12) and out of the total orchards surveyed all the surface samples were found to be medium in the availability of nitrogen both in the Nahan and Paonta Sahib blocks.

The results are in line with the findings of Verma *et al.* (1976) who reported that the cultivated soils of Kangra region of Himachal Pradesh were low to medium in available nitrogen. Kaistha *et al.* (1990) found a decreased content of different forms of available nitrogen decreased with the increase in profile depth, in the soils of North Western Himalayan region.

A decrease in available nitrogen content in the sub-surface layers has also been reported by Sharma (1988), Raina (1988) and Sharma (1990). The findings of Kumar *et al.* (2012) revealed that the mango orchard soils of Malihabad region were deficient in available nitrogen and thus these orchards need N fertilizer application at the recommended rates for improving the productivity of mango.

4.1.2.2 Available phosphorus (P)

The data depicted in table 4.2 revealed that the available phosphorus in the surface (0 to 15 cm) soils of Nahan block varied from 33.40 - 93.46 kg ha⁻¹ with a mean value of 59.63 kg ha⁻¹, whereas, in the sub-surface (15-30 cm) soils the content varied from 28.86 - 70.42 kg ha⁻¹ with an average value of 45.39 kg ha⁻¹. The respective values for Paonta Sahib block were 31.50 - 96.04 kg ha⁻¹ and 26.34 - 88.42 kg ha⁻¹ with mean values of 72.42 and 56.15 kg ha⁻¹ for surface and sub-surface soils, respectively. The distribution of available phosphorus exhibited a decreasing trend with the increase in soil depth. The values were subsequently categorised into different levels of soil fertility (table 4.12) and out of the total orchards surveyed all the surface samples were found to be high in the availability of phosphorus. The coefficient of variation of 30.80 and 30.52 per cent for available P of Nahan block and 28.25 and 35.08 per cent for Paonta Sahib block indicates that, it varied spatially in the surface and sub-surface depths, respectively. A decrease in available P with increase in soil depth has been reported by Sood *et al.* (1991) and Dongale, (1993).

The results obtained in the present investigation are in line with the finding of Raina (1988) who found medium to high levels of phosphorus in citrus growing soils of Paonta area of Himachal Pradesh. Kumar *et al.* (2012) reported that the soils of Malihabad region were medium to high in available P. The higher levels of phosphorus in many soils may be ascribed to the inherent status of P in these soils, as well as better phosphorus management practices being adopted by the farmers of that region.

Table 4.2 Available nitrogen, phosphorus and potassium (kg ha⁻¹) in the mango orchards of Sirmour district

NAHAN BLOCK							PAONTA SAHIB BLOCK						
Orchard No.	N		P		K		Orchard No.	N		P		K	
	Soil Depth (cm)							Soil Depth (cm)					
	0-15	15-30	0-15	15-30	0-15	15-30		0-15	15-30	0-15	15-30	0-15	15-30
1	361.74	345.76	58.20	43.20	356.40	298.45	1	397.64	378.53	41.22	34.50	414.64	339.76
2	391.56	378.45	69.24	57.12	534.42	439.28	2	336.87	319.85	59.04	46.34	490.24	472.32
3	403.91	391.68	33.40	29.10	356.28	288.68	3	345.73	327.59	70.42	52.46	411.65	356.10
4	324.78	309.54	49.08	35.24	386.96	292.68	4	319.48	288.79	72.18	40.16	316.40	279.14
5	383.69	357.43	46.68	33.06	394.26	376.81	5	392.87	381.29	38.86	26.34	378.25	323.80
6	375.50	358.10	63.24	51.88	336.40	288.95	6	416.96	396.41	50.08	34.72	314.20	284.74
7	395.67	379.51	60.48	49.40	526.74	512.46	7	374.65	357.97	58.42	36.44	326.54	299.60
8	376.19	353.65	68.10	54.98	428.62	354.24	8	353.55	341.19	95.40	79.20	409.27	396.45
9	370.46	364.67	34.40	30.24	572.32	524.48	9	384.10	363.09	78.40	58.36	408.46	398.42
10	410.86	393.87	52.26	38.46	459.28	396.40	10	362.78	344.28	81.72	60.24	512.78	510.32
11	412.76	391.57	66.42	42.08	594.36	582.60	11	397.46	378.36	96.04	88.42	306.80	282.63
12	355.67	334.78	76.88	59.88	438.24	310.52	12	387.45	368.64	95.40	86.20	354.18	314.76
13	367.35	348.21	90.08	68.50	352.44	287.66	13	335.56	313.41	94.80	69.44	688.28	646.52
14	345.14	325.76	44.10	32.44	382.32	348.69	14	354.65	339.76	83.88	72.26	332.68	304.80
15	389.35	366.58	36.26	28.86	564.78	544.68	15	387.23	369.26	74.16	56.32	520.24	508.74
16	377.85	356.25	42.70	30.14	578.60	554.36	16	398.51	377.78	88.26	68.12	494.06	412.72
17	367.24	343.79	84.32	63.96	492.28	378.60	17	362.41	345.14	92.20	80.32	468.32	426.88
18	357.76	335.65	76.84	53.20	326.60	280.79	18	409.87	388.54	85.16	65.28	306.62	282.71
19	368.79	348.43	93.46	70.42	456.80	426.22	19	376.56	362.19	31.50	28.16	602.96	584.20
20	387.54	368.24	46.44	35.68	376.20	285.96	20	345.87	328.46	61.28	39.62	336.70	320.02
Range	324.78-412.76	309.54-393.87	33.40-93.46	28.86-70.42	326.60-594.36	280.79-582.60	Range	319.48-416.96	288.79-396.41	31.50-96.04	26.34-88.42	306.62-688.28	279.14-646.52
Mean	376.19	357.60	59.63	45.39	445.72	388.63	Mean	372.01	353.53	72.42	56.15	419.66	387.23
C.V.(%)	5.82	6.30	30.80	30.52	20.13	26.79	C.V.(%)	7.31	7.96	28.25	35.08	25.30	27.86

4.1.2.3 Available Potassium (K)

The data depicted in table 4.2 further revealed that the available potassium in the surface (0 to 15 cm) soils of Nahan block varied from 326.60 - 594.36 kg ha⁻¹ with a mean value of 445.72 kg ha⁻¹, whereas, the sub-surface (15-30 cm) soil available potassium varied from 280.79 - 582.60 kg ha⁻¹ with an average value of 388.63 kg ha⁻¹. The respective values for Paonta Sahib block was 306.62 - 688.28 kg ha⁻¹ and 279.14 - 646.28 kg ha⁻¹ with mean values of 419.66 and 387.23 kg ha⁻¹ for surface and sub-surface soils, respectively. The distribution of available potassium exhibited a decreasing trend with the increase in soil depth. The values were subsequently categorised into different levels of soil fertility (table 4.12), out of the total orchards surveyed all the surface samples were found to be high in the availability of potassium. The coefficient of variation of 20.13 and 26.79 per cent for available K of Nahan block and 25.30 and 27.86 per cent for Paonta Sahib block shows that it varied spatially in the surface and sub-surface depths, respectively.

The available potassium was found to decrease with increase in soil depth. A decrease in potassium content in the sub-surface layers has also been reported by Singh (1987) and Sharma (1988).

The overall status of available potassium was found to be high in the mango growing soils of Kangra district. The high content of K in the soils may partly be due to the nature of parent material, which according to Pandey (1966) has at one time acquired biotite and quartz mineral assemblage. The findings of Sharma (1990) also support the results who reported high K content in apple orchard soils of district Mandi.

4.1.2.4 Available Calcium (Ca)

The data depicted in table 4.3 reveals that the available calcium in the surface layer (0 to 15 cm) of Nahan block varied from 3.94 - 6.30 cmol (p⁺) kg⁻¹ with a mean value of 5.34 cmol (p⁺) kg⁻¹, whereas, the sub-surface layer (15-30 cm) it varied from 3.54 - 5.63 cmol (p⁺) kg⁻¹ with an average value of 4.42 cmol (p⁺) kg⁻¹. The respective values for Paonta Sahib block were 3.91 - 6.32 cmol (p⁺) kg⁻¹ and 3.45 - 5.69 cmol (p⁺) kg⁻¹ with mean values of 5.05 and 4.35 cmol (p⁺) kg⁻¹ for surface and sub-surface soils, respectively. The distribution of available calcium exhibited a decreasing trend with the increase in soil depth. The values were subsequently categorised into different levels of soil fertility (table 4.12) and all the surface samples were found to be high in the availability of calcium. The coefficient of variation of

13.81 and 15.23 per cent for available Ca of Nahan block and 16.80 and 17.53 per cent for Paonta Sahib block show that Ca varied spatially in the surface and sub-surface depths, respectively.

Nair and Chamuah (1988) and Bala and Sahu (1993) have also reported calcium as dominant cation in the soils of pine forest of Himachal Pradesh. Similarly, Sharma *et al.* (2002) reported that soils of Fatehpur block in Himachal Pradesh were sufficient in calcium. The higher values of Ca in soils may be due to high content of calcium carbonate and neutral pH. Further, higher values may also be attributed to the nutrient management practices followed by the farmers of the area and also to the parent material.

4.1.2.5 Available Magnesium (Mg)

The data depicted in table 4.3 reveals that the available magnesium in the surface (0 to 15 cm) soils of Nahan block varied from 2.63 - 4.26 cmol (p⁺) kg⁻¹ with a mean value of 3.40 cmol (p⁺) kg⁻¹, whereas, in the sub-surface (15 to 30 cm) soils it varied from 2.14 - 3.89 cmol (p⁺) kg⁻¹ with an average value of 2.86 cmol (p⁺) kg⁻¹. The respective values for Paonta Sahib block were 2.18 - 4.26 cmol (p⁺) kg⁻¹ and 1.68 - 3.65 cmol (p⁺) kg⁻¹ with mean values of 3.19 and 2.66 cmol (p⁺) kg⁻¹ for surface and sub-surface soils. The coefficient of variation of 17.54 and 18.56 per cent for available Mg of Nahan block and 18.27 and 20.78 per cent for Paonta Sahib block indicates that, it varied spatially in the surface and sub-surface depths, respectively. The distribution of available magnesium exhibited a decreasing trend with the increase in soil depth. The values were subsequently categorised into different levels of soil fertility (table 4.12) and out of the total orchards surveyed all the surface samples were found to be high in the availability of magnesium.

The available Mg content decreased with an increase in soil depth. Mandal *et al.* (1990) attributed high Mg content to the organic carbon and CaCO₃ content in the soils of upper hill forests of eastern Himalayan soils. Similar findings have been reported by Kaistha and Gupta (1993) for the hill soils of Himachal Pradesh. Similarly, Sharma *et al.* (2002) reported that soils of Fatehpur block in Himachal Pradesh were sufficient in magnesium.

4.1.2.6 Sulphate sulphur (SO₄²⁻-S)

The data depicted in table 4.3 further reveals that the sulphate sulphur in the surface (0 to 15 cm) soils of Nahan block varied from 33.40 - 62.90 kg ha⁻¹ with a mean value of 46.18 kg ha⁻¹, whereas, the sub-surface sulphate sulphur varied from 25.40 - 52.80 kg ha⁻¹

Table 4.3 Exchangeable calcium, magnesium [cmol (p⁺) kg⁻¹] and available sulphur (kg ha⁻¹) in the mango orchards of Sirmour district

NAHAN BLOCK							PAONTA SAHIB BLOCK						
Orchard No.	Ca		Mg		SO ₄ ^{''} -S		Orchard No.	Ca		Mg		SO ₄ ^{''} -S	
	Soil Depth (cm)							Soil Depth (cm)					
	0-15	15-30	0-15	15-30	0-15	15-30		0-15	15-30	0-15	15-30	0-15	15-30
1	4.50	3.75	2.66	2.14	36.90	29.30	1	5.89	4.50	2.98	2.20	46.50	40.50
2	5.45	4.25	4.18	3.59	43.20	42.10	2	4.16	3.53	2.18	1.68	40.80	35.80
3	5.49	4.30	4.13	3.30	44.80	38.40	3	4.92	4.07	4.11	3.59	45.70	38.90
4	5.83	4.46	3.78	2.89	33.40	25.60	4	5.87	4.97	3.15	2.66	49.50	44.30
5	4.31	3.56	3.45	2.74	33.60	33.20	5	3.91	3.45	3.41	2.83	42.90	34.70
6	6.24	5.63	3.79	2.92	36.40	35.90	6	5.17	4.35	2.87	2.58	37.60	24.60
7	4.02	3.69	2.71	2.35	45.80	36.80	7	4.23	3.83	3.84	3.48	51.60	49.50
8	4.92	3.57	4.26	3.89	59.40	50.80	8	5.32	4.89	3.75	2.36	45.20	44.80
9	5.93	4.52	4.03	3.64	46.30	43.60	9	5.47	4.76	2.93	2.61	42.80	35.20
10	5.19	4.25	3.86	3.19	39.70	25.40	10	5.78	5.23	3.52	2.98	58.40	50.80
11	3.94	3.54	2.63	2.18	62.90	52.80	11	6.09	5.37	2.94	2.65	48.90	32.80
12	4.85	4.16	2.74	2.26	47.90	36.30	12	4.21	3.48	2.42	1.96	53.80	30.10
13	5.95	4.74	3.88	3.19	58.20	48.40	13	4.26	3.51	2.84	2.57	40.30	39.80
14	5.38	4.47	4.01	3.32	54.50	49.80	14	3.96	3.49	3.38	2.88	51.60	45.90
15	5.81	4.56	3.21	2.77	37.10	35.70	15	4.90	4.13	2.31	1.85	57.30	36.70
16	6.11	5.42	2.72	2.25	49.60	36.40	16	4.57	3.91	2.57	1.98	40.40	34.50
17	6.30	5.62	3.04	2.76	54.70	33.10	17	6.29	5.41	3.44	2.93	58.60	50.90
18	5.10	4.13	3.13	2.87	55.10	49.10	18	5.73	4.98	3.20	2.74	31.70	28.30
19	6.23	5.49	3.10	2.81	42.80	40.60	19	3.93	3.47	4.26	3.65	50.80	49.30
20	5.20	4.37	2.68	2.14	41.30	34.40	20	6.32	5.69	3.74	3.04	59.40	42.70
Range	3.94-6.30	3.54-5.63	2.63-4.26	2.14-3.89	33.40-62.90	25.40-52.80	Range	3.91-6.32	3.45-5.69	2.18-4.26	1.68-3.65	31.70-59.40	24.60-50.90
Mean	5.34	4.42	3.40	2.86	46.18	38.89	Mean	5.05	4.35	3.19	2.66	47.69	39.51
C.V.(%)	13.81	15.23	17.54	18.56	19.30	20.92	C.V.(%)	16.80	17.53	18.27	20.78	16.08	19.49

with an average value of 38.89 kg ha⁻¹. The respective values for Paonta Sahib block were 31.70 - 59.40 kg ha⁻¹ and 24.60 - 50.90 kg ha⁻¹ with mean values of 47.69 and 39.51 kg ha⁻¹ for surface and sub-surface soils. The coefficient of variation of 19.30 and 20.92 per cent for available S of Nahan block and 16.08 and 19.49 per cent for Paonta Sahib block indicated that, it varied spatially in the surface and sub-surface depths, respectively. Its content decreased with an increase in soil depth. The data depicted in table 4.12 reveal that the soils were high in sulphate sulphur.

The findings of Tripathi and Singh (1992) support the obtained results, who reported the decreasing trend of sulphur with increasing soil depth. Adequate supplies of sulphur have also been reported by Singh (1987) and Sharma (1988) in different regions of Himachal Pradesh. The medium or adequate content of S in soils of Himachal Pradesh may be due to the high content of organic matter and the nature of parent material which is gypsiferous and ferruginous limestone (Wadia, 1966).

4.1.3 Micronutrient status of soil

4.1.3.1 DTPA extractable zinc (Zn)

The data depicted in table 4.4 reveals that the DTPA extractable zinc in the surface (0 to 15 cm) soils of Nahan block varied from 1.38 - 3.90 mg kg⁻¹ with a mean value of 2.57 mg kg⁻¹, whereas, the sub-surface (15-30 cm) soil DTPA zinc varied from 1.00 - 2.97 mg kg⁻¹ with an average value of 1.89 mg kg⁻¹. The respective values for Paonta Sahib block were 1.41 - 4.06 mg kg⁻¹ and 1.02 - 2.83 mg kg⁻¹ with mean values of 2.73 and 1.88 mg kg⁻¹ for surface and sub-surface soils. The distribution of DTPA extractable zinc exhibited a decreasing trend with the increase in soil depth which may be due to lower organic matter content in the sub- surface layers. The values when categorised into different levels of soil fertility (table 4.12) indicate that in the Nahan block, 70 and 30 per cent of the surface samples were found to be medium and high in the availability of zinc, respectively, while in Paonta Sahib block, 55 and 45 per cent samples were medium and high respectively.

The results get strength from the findings of Tripathi *et al.* (1994) who found zinc to vary from 0.10 to 2.80 ppm in soils and its content decreased with increase in soil depth. The high content of available zinc in surface layer may be attributed to its more favourable pH and higher organic carbon content.

Table 4.4 DTPA - extractable zinc and copper (mg kg⁻¹) in the mango orchards of Sirmour district

NAHAN BLOCK					PAONTA SAHIB BLOCK				
Orchard No.	Zn		Cu		Orchard No.	Zn		Cu	
	Soil Depth (cm)					Soil Depth (cm)			
	0-15	15-30	0-15	15-30		0-15	15-30	0-15	15-30
1	2.50	1.97	1.39	0.64	1	3.01	2.04	2.96	1.80
2	1.57	1.15	0.79	0.47	2	2.34	1.54	1.12	0.56
3	1.38	1.00	1.96	1.02	3	2.73	1.68	1.74	1.18
4	2.84	1.91	2.29	1.39	4	1.94	1.43	3.70	2.48
5	1.63	1.27	0.87	0.43	5	2.61	1.57	2.14	1.22
6	1.69	1.31	3.83	2.58	6	2.24	1.59	1.86	1.14
7	2.43	1.65	2.39	1.86	7	3.18	2.28	3.20	2.27
8	1.55	1.04	1.78	0.98	8	3.77	2.64	3.64	2.56
9	2.93	1.98	2.86	1.92	9	2.45	1.74	3.87	2.63
10	2.98	2.09	1.54	0.72	10	2.09	1.40	1.20	0.60
11	3.16	2.78	0.96	0.56	11	3.70	2.58	2.80	1.98
12	3.42	2.81	2.52	1.43	12	3.93	2.77	0.71	0.42
13	2.82	1.89	1.73	0.97	13	3.12	2.14	0.98	0.46
14	2.91	1.92	1.92	0.72	14	4.06	2.83	0.82	0.57
15	3.90	2.97	2.16	1.17	15	1.41	1.02	3.30	2.41
16	2.06	1.35	1.08	0.60	16	3.56	2.42	2.67	2.06
17	2.19	1.49	3.32	2.32	17	1.79	1.27	1.68	0.82
18	3.32	2.75	0.93	0.47	18	3.25	2.24	0.68	0.34
19	2.53	1.68	0.86	0.41	19	1.74	1.25	1.37	0.75
20	3.60	2.80	1.64	1.23	20	1.72	1.21	0.74	0.38
Range	1.38-3.90	1.00-2.97	0.79-3.83	0.41-2.58	Range	1.41-4.06	1.02-2.83	0.68-3.87	0.34-2.63
Mean	2.57	1.89	1.84	1.09	Mean	2.73	1.88	2.06	1.33
C.V. (%)	29.00	33.81	46.32	59.07	C.V. (%)	30.01	30.31	54.12	63.52

4.1.3.2 DTPA extractable copper (Cu)

The data depicted in table 4.4 reveals that the DTPA extractable copper in the surface (0 to 15 cm) soils of Nahan block varied from 0.79 - 3.83 mg kg⁻¹ with a mean value of 1.84 mg kg⁻¹, whereas, the sub-surface (15-30 cm) DTPA extractable copper varied from 0.41 - 2.58 mg kg⁻¹ with an average value of 1.09 mg kg⁻¹. The respective values for Paonta Sahib block were 0.68 - 3.87 mg kg⁻¹ and 0.34 - 2.63 mg kg⁻¹ with mean values of 2.06 and 1.33 mg kg⁻¹ for surface and sub-surface soils. The coefficient of variation of 46.32 and 59.07 for DTPA extractable Cu of Nahan block and 54.12 and 63.52 for Paonta Sahib block indicated that, it varied spatially in the surface and sub-surface depths, respectively. The distribution of DTPA extractable copper exhibited a decreasing trend with the increase in soil depth. The values were subsequently categorised into different levels of soil fertility (table 4.12). Out of the total orchards surveyed 100 per cent surface samples were found to be high in Nahan block, while in the Paonta Sahib block 15 and 85 per cent samples were found to be medium and high, respectively, in the availability of copper.

Tripathi *et al.* (1994) and Mahajan (2001) also reported high levels of DTPA-Cu in soils of Himachal Pradesh. Badhe *et al.* (1971) have ascribed high copper contents to its positive relationship with soil organic matter content. The findings of Sharma and Choudhary (2007) revealed that the availability of copper progressively decreased with depth.

4.1.3.3 DTPA extractable Iron (Fe)

The data depicted in table 4.5 reveals that the DTPA extractable iron in the surface (0 to 15 cm) soils of Nahan block varied from 18.67 - 44.80 mg kg⁻¹ with a mean value of 30.47 mg kg⁻¹, whereas, the sub-surface (15-30 cm) DTPA extractable iron varied from 14.80 - 39.74 mg kg⁻¹ with an average value of 24.38 mg kg⁻¹. The respective values for Paonta Sahib block were 18.52 - 46.78 mg kg⁻¹ and 11.25 - 38.58 mg kg⁻¹ with mean values of 29.39 and 23.45 mg kg⁻¹ for surface and sub-surface soils, respectively. The coefficient of variation of 25.36 and 29.03 per cent for DTPA extractable Fe of Nahan block and 27.45 and 28.14 per cent for Paonta Sahib block indicates that, it varied spatially in the surface and sub-surface depths, respectively. The distribution of DTPA extractable iron exhibited a decreasing trend with the increase in soil depth. The values were subsequently categorised into different levels of soil fertility (table 4.12). Out of the total orchards surveyed all the surface samples were found to be high in the availability of iron.

Table 4.5 DTPA- extractable iron and manganese (mg kg⁻¹) in the mango orchards of Sirmour district

NAHAN BLOCK					PAONTA SAHIB BLOCK				
Orchard No.	Fe		Mn		Orchard No.	Fe		Mn	
	Soil Depth (cm)					Soil Depth (cm)			
	0-15	15-30	0-15	15-30		0-15	15-30	0-15	15-30
1	32.22	25.80	25.89	20.98	1	26.54	23.04	3.79	2.92
2	44.80	39.74	15.40	11.47	2	31.09	26.04	10.30	6.32
3	41.60	32.66	4.12	2.86	3	33.67	28.93	22.52	19.24
4	18.67	15.12	19.78	18.79	4	25.85	19.89	19.93	17.71
5	21.70	15.36	14.60	11.44	5	23.28	21.68	25.54	22.43
6	43.79	32.98	10.73	8.10	6	22.42	14.82	17.93	14.30
7	22.90	18.24	7.19	4.17	7	25.20	18.06	12.11	10.68
8	32.06	28.87	9.64	5.28	8	46.15	38.58	11.62	9.86
9	30.12	22.54	21.58	18.48	9	28.58	21.15	6.68	5.30
10	22.73	14.80	22.93	19.31	10	24.26	22.60	18.36	16.93
11	26.45	20.31	14.34	12.21	11	18.52	11.25	5.09	3.47
12	24.40	16.93	17.98	15.76	12	25.50	19.44	20.86	18.25
13	23.18	21.72	19.90	17.83	13	27.04	23.18	18.54	18.82
14	27.29	21.74	20.95	19.21	14	38.26	31.64	7.57	4.10
15	40.72	32.10	21.66	18.67	15	24.88	22.82	8.22	6.80
16	34.22	28.03	17.62	13.60	16	22.26	18.27	16.82	13.72
17	29.09	25.11	6.51	4.98	17	29.48	22.83	16.70	14.92
18	26.34	17.68	7.85	5.80	18	46.78	34.26	26.44	21.10
19	36.28	30.54	22.52	19.23	19	42.69	30.38	15.93	13.65
20	30.75	27.38	19.50	17.52	20	25.44	20.10	24.01	20.24
Range	18.67-44.80	14.80-39.74	4.12-25.89	2.86-20.98	Range	18.52-46.78	11.25-38.58	3.79-26.44	2.92-22.43
Mean	30.47	24.38	16.03	13.28	Mean	29.39	23.45	15.45	13.04
C.V. (%)	25.36	29.03	39.77	46.10	C.V. (%)	27.45	28.14	44.80	49.16

The higher Fe contents may be attributed to slightly acidic to near neutral soil reaction and presence of gypsiferous and ferruginous limestone parent material containing hematite and limonite minerals (Wadia, 1966). Reports also confirm an inverse relationship between availability of Fe and soil pH and its irregular distribution in the soil solum (Jalali *et al.* 1989 and Mishra *et al.* 1990).

4.1.3.4 DTPA extractable Manganese (Mn)

The data depicted in table 4.5 reveals that the DTPA extractable manganese in the surface and sub-surface soils of Nahan block varied from 4.12 - 25.89 mg kg⁻¹ with a mean value of 16.03 mg kg⁻¹, and 2.86 - 20.98 mg kg⁻¹ with an average value of 13.28 mg kg⁻¹, respectively. The respective values for Paonta Sahib block were 3.79 - 26.44 mg kg⁻¹ and 2.92 - 22.43 mg kg⁻¹ with mean values of 15.45 and 13.04 mg kg⁻¹ for surface and sub-surface soils. The coefficient of variation of 39.77 and 46.10 per cent for DTPA extractable Mn of Nahan block and 44.80 and 49.16 per cent of Paonta Sahib block indicated that, it also varied spatially in the surface and sub-surface depths, respectively. The distribution of DTPA extractable manganese exhibited a decreasing trend with the increase in soil depth. Out of the total orchards surveyed all the surface samples were found to be high in the availability of manganese (table 4.12).

The results are in line with the findings of Kaul (1968) who observed a decrease in Mn content with the increasing depth of soils. Tripathi *et al.* (1994) ascribed higher Mn to the positive relationship of available Mn with the organic carbon contents in soils.

4.2 NUTRIENT INDICES OF SOIL

A perusal of data in table 4.14 of the surface layers reveals that no samples of Sirmour district fall under low category. All the soil samples of Sirmour district were rich in P, K, Ca, Mg, SO₄²⁻ S, Fe and Mn.

Nutrient indices indicate that soils of the district, as regards the nutrient status are high in available phosphorus (2.93), potassium (3.00), available calcium (3.00), available magnesium (3.00), sulphate sulphur (3.00), DTPA copper (3.00), iron (2.36), manganese (2.83) and zinc (2.38). However, with respect to available nitrogen (1.83) soils are medium in nutrient status.

Nutrient indices of the sub-surface layers indicate a similar trend thereby indicating high available phosphorus (2.90), potassium (2.93), available calcium (3.00), available magnesium (3.00), sulphate sulphur (2.93), DTPA copper (3.00) and manganese (2.80). As in the case of surface soils, the nutrient index for available nitrogen (1.70) and DTPA extractable Zn (2.23), are medium .

4.3 NUTRIENT CONCENTRATION IN THE LEAVES OF MANGO

The leaf samples of mango were also analyzed for their nutrient element contents and the results are presented below:

4.3.1 Macronutrients

The leaf N, P and K contents in mango orchards ranged from 1.18 to 2.52 per cent , 0.24 to 0.46 per cent and 0.64 to 1.60 per cent with mean values of 1.83, 0.36 and 1.01 per cent, respectively (table 4.6) for Nahan block, while, for Paonta Sahib block, the leaf N, P and K contents ranged from 1.40 to 2.56 per cent , 0.25 to 0.42 per cent and 0.64 to 1.46 per cent with mean values of 1.98, 0.33 and 1.00 per cent, respectively The coefficient of variation of 23.38 , 18.13 and 22.80 per cent of Nahan block, while 21.20 , 19.30 and 22.78 per cent of Paonta Sahib block for leaf N, P and K, respectively, indicates that, these varied spatially with respect to the orchards. The data in Table 4.13 shows that only 30 and 20 per cent leaf samples were medium in nitrogen, while 70 and 80 per cent were found to be in high category for Nahan and Paonta Sahib blocks, respectively. For P, 10 and 30 per cent samples were found in medium category and 90 and 70 per cent were found in high category for both the blocks, respectively. In case of K, 25 and 40 per cent leaf samples were found in medium, and 75 and 60 per cent found in high categories for both blocks respectively.

The results are in conformity with the findings of Kumar and Rehalia (2007) who recorded an average of 2.23 per cent leaf nitrogen, 0.12 per cent phosphorus and 0.64 per cent potassium in mango under healthy conditions. Chadha *et al.* (1980) observed that there was decreasing trend of leaf P content in mango from November to July with the advancement of season, thereafter an increasing trend was registered.

The leaf Ca, Mg and S contents Table ranged from 0.84 to 4.95 per cent, 0.42 to 1.41 per cent and 0.16 to 0.45 per cent with mean values of 2.88, 0.84 and 0.31 per cent, respectively (table 4.7) for Nahan block, while, for Paonta Sahib block, the leaf Ca, Mg and S

Table 4.6 Leaf nitrogen, phosphorus and potassium contents (per cent) in mango orchards of Sirmour district

NAHAN BLOCK				PAONTA SAHIB BLOCK			
Orchard No.	N	P	K	Orchard No.	N	P	K
1	1.63	0.41	0.76	1	2.56	0.40	0.95
2	1.76	0.31	1.20	2	1.40	0.32	1.42
3	1.68	0.28	0.92	3	1.42	0.39	0.79
4	1.32	0.27	0.94	4	1.63	0.42	0.99
5	2.34	0.34	0.91	5	1.52	0.37	0.80
6	1.32	0.35	0.92	6	1.72	0.25	1.02
7	1.44	0.39	0.79	7	2.18	0.40	0.85
8	1.76	0.32	0.64	8	2.52	0.25	0.77
9	1.18	0.40	0.97	9	2.24	0.29	1.02
10	2.42	0.33	0.90	10	1.64	0.32	0.96
11	1.92	0.39	1.60	11	2.28	0.33	0.81
12	1.86	0.38	1.17	12	2.46	0.41	1.15
13	1.98	0.45	1.03	13	1.74	0.25	0.99
14	1.36	0.38	0.92	14	2.20	0.30	0.85
15	2.42	0.42	1.37	15	2.24	0.27	0.64
16	2.52	0.24	1.05	16	2.52	0.25	1.17
17	2.36	0.46	1.24	17	1.68	0.31	1.46
18	1.86	0.40	0.73	18	1.68	0.37	1.30
19	2.16	0.24	1.09	19	1.46	0.25	0.85
20	1.34	0.34	1.19	20	2.42	0.41	1.28
Range	1.18-2.52	0.24 - 0.46	0.64-1.60	Range	1.40-2.56	0.25-0.42	0.64-1.46
Mean	1.83	0.36	1.01	Mean	1.98	0.33	1.00
C.V. (%)	23.38	18.13	22.80	C.V. (%)	21.20	19.30	22.78

Table 4.7 Leaf calcium, magnesium and sulphur (per cent) in mango orchards of Sirmour district

NAHAN BLOCK				PAONTA SAHIB BLOCK			
Orchard No.	Ca	Mg	S	Orchard No.	Ca	Mg	S
1	4.95	0.88	0.32	1	3.20	0.85	0.33
2	3.21	0.97	0.35	2	3.27	1.27	0.17
3	3.78	0.83	0.37	3	3.67	1.30	0.14
4	4.84	0.58	0.37	4	4.02	0.62	0.43
5	4.08	0.44	0.34	5	3.08	0.48	0.32
6	4.13	0.89	0.18	6	3.31	0.88	0.37
7	3.68	1.16	0.35	7	3.64	0.64	0.36
8	3.93	0.48	0.40	8	2.56	0.92	0.34
9	4.62	0.72	0.41	9	0.58	1.32	0.19
10	3.81	0.98	0.30	10	0.44	1.47	0.28
11	1.06	0.96	0.44	11	3.36	0.89	0.34
12	1.15	0.53	0.32	12	3.06	1.18	0.29
13	4.84	0.61	0.45	13	3.00	1.38	0.19
14	1.16	0.42	0.20	14	3.39	0.55	0.35
15	1.43	0.90	0.22	15	2.89	0.79	0.17
16	1.47	1.41	0.30	16	2.80	1.02	0.27
17	0.84	1.32	0.16	17	3.24	1.46	0.36
18	0.95	0.49	0.27	18	0.84	0.65	0.20
19	2.57	1.27	0.33	19	0.95	0.50	0.40
20	1.19	1.03	0.20	20	1.03	0.52	0.28
Range	0.84-4.95	0.42-1.41	0.16-0.45	Range	0.44-4.02	0.48-1.47	0.14-0.43
Mean	2.88	0.84	0.31	Mean	2.61	0.93	0.29
C.V. (%)	53.79	36.05	27.31	C.V. (%)	43.77	36.73	29.59

contents ranged from 0.44 to 4.02 per cent, 0.48 to 1.47 per cent and 0.14 to .43 per cent with mean values of 2.61, 0.93 and 0.29 per cent, respectively. The coefficient of variation of 53.9 , 36.05 and 27.31 of Nahan block, while 43.77 , 36.73 and 29.59 per cent for Paonta Sahib block for leaf Ca, Mg and S indicates that, these varied spatially with respect to the orchards. Table 4.13 showed that 40 per cent orchards in Nahan and 25 per cent in Paonta Sahib blocks had low levels of calcium, whereas 60 and 75 per cent orchards in respective blocks were medium in calcium. Similarly, 20 and 10 per cent orchards in Nahan and Paonta Sahib blocks were medium, while 80 and 90 per cent were high in magnesium, respectively. The sulphur status of leaves showed that 10 and 90 per cent orchards in Nahan and 25 and 75 per cent orchards in Paonta Sahib blocks fall in low and medium categories, respectively. The observations are in agreement with those of Kumar and Rehalia (2007) who observed similar trend of leaf Ca and Mg in mango orchards in Kangra district.

Devrani and Sant Ram (1980) while studying the effect of age and flush on the mineral content of mango leaf, found that there was higher level of leaf calcium content during March flush (I) followed by July (II) and September (III) flushes. In general the leaf Ca has shown increasing trend for 6 months and were stable thereafter up to 12 months in first flush. There were no change in leaf Ca during II flush and highly fluctuating in III flush.

4.3.2 Micronutrients

The leaf Zn, Cu, and Fe in Nahan orchards ranged from 13.60 to 87.30 ppm ,14.50 to 83.10 ppm and 214.20 to 413.30 ppm with mean value of 46.24 ppm, 43.71 ppm and 296.63 ppm, respectively (Table 4.8) for Nahan block, while, for Paonta Sahib orchards, the leaf Zn, Cu and Fe ranged from 14.40 to 84.70 ppm ,14.40 to 78.10 ppm and 214.20 to 437.40 ppm with mean value of 38.02 ppm, 42.23 ppm and 344.45 ppm, respectively. The CV of 44.39, 56.19 and 25.15 per cent for Nahan block, while 52.09 , 54.12 and 20.64 per cent for Paonta Sahib block for leaf Cu, Zn and Fe indicated that, these varied spatially with respect to the orchards. As per the data in the Table 4.13 the leaf samples of mango were low to medium in Zn and medium to high in Cu for both the blocks. For Fe, 40 and 10 per cent leaf samples were in medium category, whereas, 60 and 90 per cent were in high categories for both the blocks, respectively.

The findings of Kumar *et al.* 2012 support the results who reported similar results of leaf Cu, Zn and Fe with mean value of 26.50 ppm, 33.60 ppm and 396.00 ppm in mango leaf samples at Malihabad region.

Table 4.8 Leaf zinc, copper, iron and manganese contents (ppm) in mango orchards of Sirmour district

NAHAN BLOCK					PAONTA SAHIB BLOCK				
Orchard No.	Zn	Cu	Fe	Mn	Orchard No.	Zn	Cu	Fe	Mn
1	30.70	47.60	299.20	177.30	1	14.40	47.50	312.20	149.90
2	24.50	43.10	353.80	88.20	2	24.20	44.20	287.70	151.30
3	35.50	29.80	239.40	124.80	3	22.90	41.50	380.40	185.20
4	87.30	27.30	406.20	154.30	4	16.90	55.30	296.40	164.50
5	19.80	52.60	223.90	135.10	5	21.60	24.30	297.60	121.80
6	30.30	59.70	301.90	88.20	6	34.50	75.40	363.10	180.80
7	32.00	50.10	413.30	75.10	7	79.30	44.70	345.50	157.10
8	22.70	38.20	228.40	186.60	8	42.60	56.10	426.30	81.40
9	31.60	38.90	214.20	173.30	9	34.40	14.40	257.10	134.80
10	20.40	77.30	218.80	182.10	10	24.90	61.20	376.20	178.50
11	60.40	58.20	356.90	142.20	11	67.90	38.60	226.60	169.70
12	63.10	83.10	231.60	171.80	12	58.40	22.60	214.20	178.10
13	47.80	26.80	381.30	151.70	13	28.30	35.10	387.80	196.80
14	29.30	14.50	215.80	138.90	14	19.20	33.10	402.30	76.90
15	17.80	71.40	408.90	178.30	15	78.50	18.80	269.80	85.50
16	77.50	28.30	258.60	106.40	16	84.70	78.10	427.90	128.20
17	69.30	79.60	287.90	122.40	17	51.80	15.30	433.20	163.10
18	81.50	15.80	396.40	194.30	18	26.60	19.70	437.40	92.40
19	13.60	33.80	262.20	110.80	19	62.50	17.20	332.30	191.40
20	79.10	48.60	233.90	128.10	20	50.90	17.30	414.90	132.80
Range	13.60-87.30	14.50-83.10	214.20-413.30	75.10-194.30	Range	14.40-84.70	14.40-78.10	214.20-437.40	76.90-196.80
Mean	43.71	46.24	296.63	141.50	Mean	42.23	38.02	344.45	146.01
C.V. (%)	56.19	44.39	25.15	25.35	C.V. (%)	54.12	52.09	20.64	26.07

Devrani and Santram (1980) observed that the Cu content in mango increased slowly along the advancement of season. The highest level of leaf Cu content attained in 5th (120 ppm), 7th (160 ppm) and 9th (160 ppm) month of leaf age on first (March), second (July) and third (September) flushes respectively. Samra *et al.* (1979) found that Fe content in fruiting terminals was higher than non fruiting terminals of Dashehri (241.0 and 216.0 ppm), Lukhnow Safeda (197.0- 188.0 ppm) and Chausa (185.0-181.0 ppm), respectively.

The leaf Mn (table 4.8) ranged from 75.10 to 194.30 ppm with mean value of 141.50 ppm for Nahan block, while, for Paonta Sahib block, the leaf Mn ranged from 76.90 to 196.80 ppm with the mean value of 146.01 ppm. The data in the table 4.13 shows that the plants had medium to high level of manganese in both the blocks, with 50 per cent samples falling in either category. The results are in accordance with those of Kumar *et al.* 2012 who reported the mean value of Mn was 146.50 ppm in mango leaf samples, respectively.

4.4 RELATIONSHIP OF SOIL PROPERTIES WITH NUTRIENT CONTENT IN THE SOILS

The perusal of the data in Table 4.9 shows the relationship of nutrient elements with soil pH, EC and organic carbon contents. The data revealed that the soil pH of the surface layers was significantly and positively correlated with available N ($r = 0.51^{**}$) only. For the sub-surface layers, the soil pH was significantly and positively correlated with available N ($r = 0.40^*$) but, significantly and negatively correlated with available K ($r = -0.32^*$). The relationships of pH with micronutrients were found to be negative but did not reach the level of significance.

Soil pH is considered as the driver of soil fertility because of its direct impact on nutrient availability and plant growth. It has been reported that solubility and availability of nutrient ions are pH dependent and the micronutrient availability decreases 100- fold with each unit increase in pH (Tisdale *et al.* 1995). Negative relationship of pH with available micronutrients cations has been reported by Rai *et al.* (1972) and Bhandari and Randhawa (1985). Verma and Tripathi (1982) reported that the soil pH had negative co-relation with total Fe in soils of Kangra valley. Katyal and Aggarwal (1982) have also depicted an inverse relationship of soil pH with available micronutrient cations viz., Fe, Mn and Cu and Mishra *et al.* (1990) observed a positive relationship of soil pH with available P in foot hills of Himalayas.

Table 4.9 Relationships (r-values) of nutrient content in the soils with the soil properties

Property Nutrient element	pH		EC		OC	
	0-15	15-30	0-15	15-30	0-15	15-30
N	0.51**	0.40**	0.11	0.04	0.53**	0.49**
P	-0.11	-0.26	0.22	0.19	0.52**	0.42**
K	-0.28	-0.32*	0.28	0.30*	0.31*	0.39**
Ca	0.24	0.22	-0.16	-0.16	-0.22	-0.03
Mg	0.25	0.23	-0.17	-0.16	-0.18	-0.13
S	-0.10	-0.11	0.04	0.05	0.14	0.01
Cu	-0.13	-0.17	-0.31*	-0.34*	-0.11	-0.13
Fe	-0.09	-0.19	-0.04	-0.04	-0.19	-0.26
Mn	-0.18	-0.05	0.01	-0.02	0.14	0.12
Zn	-0.09	-0.15	-0.04	0.02	0.20	0.17

* Significant at 5 per cent level

** Significant at 1 per cent level

The electrical conductivity of the surface layers was found to be significantly and negatively correlated with available Cu ($r = -0.31^*$). For the sub-surface layers, a significantly positive correlation existed between EC and K ($r = 0.30^{**}$) and negative and significant with available Cu ($r = -0.34^*$) (table 4.9). The relationship obtained for electrical conductivity are supported by the findings of Ramana Murthy and Srivastava (1994) who observed a positive and significant correlation of EC with available macronutrients. Trivedi *et al.* (2010), however, also found a negative and highly significant relation of EC with available P in the soils of Madhya Pradesh.

The organic carbon content in the surface soils was significantly and positively correlated with available N ($r = 0.53^{**}$), P ($r = 0.52^{**}$) and K ($r = 0.31^*$). For the sub-surface layers the organic carbon was found to be positively correlated with soil N ($r = 0.49^{**}$), P ($r = 0.42^{**}$), and K ($r = 0.39^*$) which were found to be significant (table 4.9). The significant and positive relationship of organic matter with N content of soils is obvious since bulk of the total N in soils is present in organic combinations.

Organic matter besides being a major source of nutrient ions such as N and P, promotes the availability of micronutrients through its chelating effects (Raina and Goswami, 1988). The studies of Bhandari and Randhawa (1985) point to a positive correlation of

organic carbon with available micronutrient elements in soils of Himachal Pradesh. Similar results have also been reported by Singh (1987) and Raina (1988) in orchard soils of district Kinnaur and Sirmour, respectively. The work of Tripathi *et al.* 1994 further support the contention that DTPA Mn was significantly correlated with organic carbon in different soil profiles of Himachal Pradesh.

Wu *et al.* 2010 studied the relationship between micronutrient availability and some major soil properties and concluded that pH and organic matter are the most important properties which controls micronutrient availability. Tundup and Akbar (2014) also depicted a positive and highly significant relationship of DTPA Zn ($r = 41^{**}$) and Cu ($r = 25^*$) with organic carbon. It can be observed that Zn and Fe content increases with the increase in soil organic matter.

4.5 RELATIONSHIPS OF SOIL PROPERTIES AND NUTRIENT CONTENTS WITH PLANT NUTRIENTS

The data presented in table 4.10 shows that the surface soil pH had a significantly negative relationship with leaf Zn ($r = -0.34^*$). The electrical conductivity of the soil was found to be significant and positively correlated with leaf Cu ($r = 0.32^*$). The OC content of the soil was significant and positively correlated with the leaf S ($r = 0.36^*$). The available N in the soil was significant and positively correlated with leaf N (0.34^*).

Table 4.10 Relationships (r-values) of nutrient content in the leaves with the soil properties and soil nutrient contents at 0-15 cm depth

Leaf Soil	N	P	K	Ca	Mg	S	Cu	Fe	Mn	Zn
pH	-0.25	-0.02	-0.05	0.14	-0.22	0.29	-0.1	0.01	-0.06	-0.34*
EC	0.26	0.10	0.06	-0.28	0.02	-0.16	0.32*	0.21	-0.03	-0.15
OC	-0.05	-0.25	-0.02	-0.16	0.28	-0.36**	0.11	-0.12	0.14	-0.13
N	0.34*	-0.08	0.09	-0.10	0.05	0.11	0.20	-0.14	-0.10	0.01
P	-0.53**	-0.06	0.10	-0.08	-0.34*	-0.12	-0.02	0.28	0.04	0.11
K	-0.01	-0.27	0.24	-0.37	-0.15	-0.37	-0.09	-0.02	-0.14	-0.01
Ca	0.11	0.08	0.18	-0.09	0.17	-0.07	-0.02	-0.01	-0.16	0.27
Mg	-0.26	-0.26	-0.30*	0.21	0.78**	0.30*	-0.18	-0.05	-0.04	-0.25
S	0.15	0.25	0.02	-0.27	-0.01	0.24	-0.26	-0.01	0.11	0.27
Cu	0.05	0.09	-0.28	0.15	-0.03	-0.07	0.26	-0.13	-0.22	0.13
Fe	-0.10	-0.19	0.10	-0.16	0.05	-0.14	-0.11	0.16	-0.37	-0.3
Mn	-0.22	0.14	0.23	0.03	-0.07	0.14	-0.02	0.09	0.31*	-0.16
Zn	0.25	0.18	0.11	-0.13	-0.03	-0.07	0.17	0.16	0.17	0.16

* Significant at 5 per cent level

** Significant at 1 per cent level

The P content in the soil was significant and negatively correlated with leaf N ($r = -0.53^{**}$), and leaf Mg ($r = -0.34^*$). The available K and Ca of surface soils did not show any significant correlations with leaf nutrients. The soil Mg was significant and positively correlated with leaf Mg ($r = 0.78^{**}$) and leaf S ($r = 0.30^*$), while negatively correlated with leaf K ($r = -0.30^*$).

The S, Fe, Cu and Zn content in the soil were also not significantly correlated with leaf nutrient contents. The available Mn in the soil was significant and positively correlated with leaf Mn ($r = 0.31^*$).

The data in the Table 4.11 shows the relationships of sub surface soil characteristics with leaf nutrients. The sub-surface soil pH was found to be significant and negatively correlated with leaf Mg ($r = -0.36^{**}$). The electrical conductivity was significantly and negatively correlated with leaf Ca ($r = -0.31^*$). The OC content in the soil was significantly and positively correlated with leaf Mg ($r = 0.32^*$), while it was negatively correlated with leaf S ($r = -0.35^{**}$). The P content in soil was significant and positively correlated with leaf Mg ($r = 0.36^{**}$). The available K in the soil was significant and positively correlated with leaf Mg ($r = 0.44^{**}$), while it was negatively correlated with leaf P ($r = -0.31^*$).

Table 4.11 Relationships (r-values) of nutrient content in the leaves with the soil properties and soil nutrient contents at 15-30 cm depth

Leaf Soil	N	P	K	Ca	Mg	S	Cu	Fe	Mn	Zn
pH	0.27	-0.08	-0.06	-0.07	-0.36 ^{**}	0.20	-0.13	-0.12	-0.17	0.08
EC	0.29	0.15	0.04	-0.31 [*]	0.12	-0.14	0.27	0.18	0.02	-0.11
OC	-0.06	-0.26	-0.02	-0.16	0.32 [*]	-0.35 ^{**}	0.11	-0.12	0.13	-0.11
N	0.21	-0.10	0.05	-0.05	0.04	0.13	0.15	-0.13	-0.21	0.01
P	0.29	-0.11	0.07	-0.02	0.36 ^{**}	-0.11	-0.05	0.21	-0.12	0.10
K	0.02	-0.31 [*]	0.21	-0.25	0.44 ^{**}	-0.07	0.03	0.11	0.04	-0.05
Ca	0.16	0.04	0.22	-0.24	0.27	-0.15	0.01	0.06	-0.03	0.06
Mg	-0.30 [*]	0.09	-0.27	0.14	0.68 ^{**}	0.27	-0.21	-0.12	0.22	-0.24
S	-0.11	0.11	-0.01	-0.19	0.23	0.33 [*]	-0.28	0.19	0.08	-0.02
Cu	0.09	0.06	-0.27	0.15	0.02	-0.08	0.28	-0.07	-0.23	0.21
Fe	-0.10	-0.19	0.07	-0.11	0.13	-0.17	-0.11	0.18	-0.44 ^{**}	-0.32 [*]
Mn	-0.22	0.13	0.23	-0.02	-0.05	-0.01	-0.03	0.10	0.29	-0.11
Zn	0.24	0.22	0.18	-0.20	-0.08	-0.03	0.23	0.14	0.14	0.23

* Significant at 5 per cent level

** Significant at 1 per cent level

The Mg content in soil found significant and positively correlated with leaf Mg ($r = 0.68^{**}$) while, negatively correlated with leaf N ($r = -0.30^*$). The available S in the soil was significant and positively correlated with leaf S ($r = 0.33^*$). The available Fe in the soil was significantly negatively correlated with leaf Mn ($r = -0.44^{**}$) and Zn ($r = -0.32^*$). All the other relationships varied but did not reach the level of significance.

According to Anderson and Albrigo (1977) more significant correlation coefficient occurred with surface soils in macronutrient elements as compared to sub-surface soils. Sharma and Bhandari (1992) and Awasthi *et al.* 1998 also reported significant and positive correlation among leaf and soil samples. Awasthi *et al.* 1999 found negative and significant correlation between leaf N and soil K of peach orchards in Sirmour.

Various types of correlations obtained or lack of correlation between any soil or plant nutrient may be due to the interaction involved between them. The fact that correlation were not very perfect for some nutrient elements may also be due to the influence of weather, size of crop, time of sampling, ion antagonism and the method of estimation. The highly significant correlations indicate that either of the two measurements may be satisfactorily used to predict the nutrient status of the orchards (Sharma and Bhandari, 1992).

Table 4.12 Status of Soil Nutrients in Mango orchards of Sirmour District

Soil Nutrient	NAHAN BLOCK			PAONTA SAHIB BLOCK		
	Per cent samples			Per cent samples		
	Low	Medium	High	Low	Medium	High
OC	-	15	85	-	15	85
N	-	100	-	-	100	-
P	-	-	100	-	-	100
K	-	-	100	-	-	100
Ca	-	-	100	-	-	100
Mg	-	-	100	-	-	100
S	-	-	100	-	-	100
Cu	-	-	100	-	15	85
Fe	-	-	100	-	-	100
Mn	-	-	100	-	-	100
Zn	-	70	30	-	55	45

Table 4.13 Status of leaf nutrients in Mango orchards of Sirmour District

Leaf Nutrient	NAHAN BLOCK			PAONTA SAHIB BLOCK		
	Per cent samples			Per cent samples		
	Low	Medium	High	Low	Medium	High
N	-	30	70	-	20	80
P	-	10	90	-	30	70
K	-	25	75	-	40	60
Ca	40	60	-	25	75	-
Mg	-	20	80	-	10	90
S	10	90	-	25	75	-
Cu	-	70	30	-	75	25
Fe	-	40	60	-	10	90
Mn	-	50	50	-	50	50
Zn	15	85	-	15	85	-

Table 4.14 Soil Nutrient Indices of Mango orchards in Sirmour District

Leaf Nutrient	Soil Depth	
	Surface (0-15 cm)	Sub- Surface (0-15 cm)
N	Medium	Medium
P	High	High
K	High	High
Ca	High	High
Mg	High	High
S	High	High
Cu	High	High
Fe	High	High
Mn	High	High
Zn	High	Medium

Chapter-5

SUMMARY AND CONCLUSION

The studies entitled “**Soil and Plant Nutrient Contents in Mango Orchards of Sirmour District of Himachal Pradesh**” were carried out during 2017 in the Paonta and Nahan blocks of Sirmour district of Himachal Pradesh with the objective to study the nutritional and fertility status of mango orchards and the relationship between soil properties and leaf nutrient contents. Soil and plant samples from 40 representative mango orchards of Sirmour district were collected. Soil samples were collected from two depths of 0-15 and 15-30 cm at each place and analysed for organic carbon, pH, EC, available macro and micronutrient elements.

Leaf samples were collected from commercially important cultivar of mango namely, “Dashehri” as per sampling time recommended by Tandon (1989). Leaf samples were collected from the orchards from which soil samples were also collected and analysed for all macro and micronutrient elements. The results obtained are summarized as below:

5.1 SOIL FERTILITY STATUS

5.1.1 Physico-chemical properties of the soils

In the surface and sub-surface depths, pH varied from 6.47 to 7.58 and 6.76 to 7.65 with the mean values of 7.07 and 7.18. The EC ranged from 0.25 to 0.68 and 0.21 to 0.54 dS m⁻¹, with mean values of 0.49 and 0.38 dS m⁻¹ in the surface and sub-surface depths, respectively. The respective contents of organic carbon in surface and sub-surface depths ranged from 12.56 to 22.75 g kg⁻¹ and 10.45 to 21.15 g kg⁻¹ with mean values of 18.18 and 16.03 g kg⁻¹. The soil pH was nearly neutral in reaction and showed an increasing trend with depth, while the EC and organic carbon contents decreased with the increase in soil depth.

5.1.2 Macronutrient status of soil

Available N content ranged from 319.48 to 416.96 and 288.79 to 396.41 kg ha⁻¹ with mean values of 374.10 and 355.56 kg ha⁻¹ in surface and sub-surface depths, respectively. The soils of the district were medium in available N contents and its availability decreased with soil depth. In surface soils, available P contents ranged from 31.50 to 96.04 kg ha⁻¹ with

a mean value of 66.03 kg ha⁻¹, whereas, in sub-surface soils, it ranged from 26.34 to 88.42 kg ha⁻¹ with the mean value of 50.77 kg ha⁻¹. It can be inferred that soils of mango orchards of Sirmour district were high in available P contents. Surface soils have higher available P content as compared to sub-surface depth. In surface depth, available K content ranged from 306.62 to 688.28 kg ha⁻¹ with the mean value of 432.69 kg ha⁻¹ and in sub-surface depth, it ranged from 279.14 to 646.52 kg ha⁻¹ with the mean value of 387.93 kg ha⁻¹. The soils were also high in available K contents. Hundred per cent samples were medium in available N whereas, 100 per cent soils were high in available P and K, respectively.

The neutral normal ammonium acetate extractable Ca and Mg contents ranged from 3.91 to 6.32 and 2.18 to 4.26 [cmol (p⁺) kg⁻¹], with mean values of 5.19 [cmol (p⁺) kg⁻¹] and 3.30 [cmol (p⁺) kg⁻¹], respectively in the surface depth. In the sub-surface depth, their contents ranged from 3.45 to 5.69 and 1.68 to 3.89 [cmol (p⁺) kg⁻¹] with the mean values of 4.39 and 2.76 [cmol (p⁺) kg⁻¹], respectively. The SO₄⁻-S contents in the surface and sub-surface depths ranged from 31.70 to 62.90 and 24.60 to 52.80 kg ha⁻¹ with the mean values of 46.94 and 39.20 kg ha⁻¹, respectively. The SO₄⁻-S decreased with the increase in soil depth. Soils of the district were high in availability status with respect to available Ca, Mg and SO₄⁻-S may be due to parent material of the soils. All soils (100%) were found high in available Ca, Mg and SO₄⁻-S contents.

5.1.3 Micronutrient status of soil

DTPA extractable Cu contents of the soils ranged from 0.68 to 3.87 and 0.34 to 2.63 mg kg⁻¹ with mean values of 1.95 and 1.21 mg kg⁻¹ in the surface and sub-surface depths, respectively. DTPA extractable Zn content of the soils ranged from 1.38 to 4.06 mg kg⁻¹ with a mean value of 2.65 mg kg⁻¹ in surface depth. In sub-surface depth, DTPA extractable Zn content varied from 1.00 to 2.97 mg kg⁻¹ with the mean value of 1.89 mg kg⁻¹. Availability of DTPA extractable Fe ranged between 18.52 to 46.78 mg kg⁻¹ in surface depth and 11.25 to 39.74 mg kg⁻¹ in sub-surface depth with mean values of 29.93 and 23.92 mg kg⁻¹. About 24 and 83 per cent soils were medium in DTPA Cu and Zn whereas 100 per cent soils were high in DTPA Fe.

DTPA extractable Mn content varied from 3.79 to 26.44 and 2.86 to 22.43 mg kg⁻¹ with mean value of 15.74 and 13.16 mg kg⁻¹ in the surface and sub-surface depths,

respectively. About 96 per cent soils were high in Mn contents. Like available macronutrient elements, micronutrient elements were also found to decrease with soil depth.

5.2 SPATIAL VARIABILITY OF NUTRIENT ELEMENTS IN SOILS

The coefficient of variations for available macronutrients (5.82-35.08%) and micronutrients (29.00-63.52%) was high. Therefore, to delineate the deficiency and sufficiency areas for micronutrients, there is need for more detailed survey as it is difficult to give a generalized picture of their status besides their limits of deficiency and sufficiency being very narrow. High coefficient of variations may be due to variation in parent materials and orchard management practices.

5.3 NUTRIENT INDICES OF SOIL

Nutrient indices indicate that the surface soils of the district were high in available P (2.93), K (3.00), Ca (3.00), Mg (3.00), SO₄-S (3.00), DTPA extractable Cu (3.00), Fe (2.36) and Mn (2.83). However, with respect to available N (1.83), DTPA extractable Zn (1.93). All the surface soils had high supplies of P, K, Ca, Mg, S, Cu, Mn and Zn.

In the sub-surface layer the nutrient status was high in available P (2.90), K (2.93), Ca (3.00), Mg (3.00), SO₄-S (2.93), DTPA Cu (3.00), Fe (2.63) and Mn (2.80). However, with respect to available N (1.70) and Zn (1.69) soils were medium in their status. All the sub-surface soils (100%) had high supplies of P, K, Ca, Mg, S, Cu, Fe and Mn. However, 100, 83, and 24 per cent of the sub-surface soils fell under medium categories for N, Zn and Cu, respectively.

5.4 LEAF NUTRIENT STATUS

Leaf N, P and K contents varied from 1.18 to 2.56, 0.24 to 0.46 and 0.64 to 1.60 per cent, with the mean values of 1.90, 0.34 and 1.01 per cent, respectively. Majority of soils were medium to high in N, P and K contents.

Leaf Ca, Mg and S contents ranged from 0.44 to 4.84, 0.42 to 1.47 and 0.14 to 0.45 per cent with the mean values of 2.75, 0.89 and 0.30 per cent, respectively. The Cu, Zn and Fe contents varied from 14.40 to 83.10, 13.60 to 87.30 and 214.20 to 437.40 per cent with the mean values of 42.13, 42.97 and 320.54 per cent, respectively. Similarly, Mn content in the leaf varied from 75.10 to 196.80 per cent with the mean values of 143.75 per cent. Only 20,

60 and 40 per cent of the soils fell in low category for Ca, S and Zn respectively whereas, 75, 80, 68, 85, 28, 75 and 50 per cent of soils fell in high category for N, P, K, Mg and Cu, Fe and Mn respectively.

5.5 SPATIAL VARIABILITY OF NUTRIENT ELEMENTS IN PLANTS

The coefficients of variation for the different nutrient elements were high and varied from 18.13-56.19%, suggesting unequal availability of nutrient elements in different orchards. The high coefficient of variation in plants may be due to high variations in soils.

5.6 RELATIONSHIP OF SOIL PROPERTIES WITH NUTRIENT CONTENTS IN SOILS

The soil pH of the surface depth was found to be positively and significantly correlated with soil N but negatively correlated to soil P and K. In sub-surface depth, the positive correlation was observed with soil pH and N and negative with P and K. The electrical conductivity of the surface and sub-surface depth had positive and significant relationship with soil K. The organic carbon was found to have a significant and positive relationship with soil available N, P and K in both the surface and sub-surface depths.

5.7 RELATIONSHIP OF SOIL NUTRIENT CONTENT WITH PLANT NUTRIENTS

The soil pH was negatively correlated with leaf Mg and Zn. The electrical conductivity of the soil was found to positively correlated with leaf Cu and negatively correlated with leaf Ca. The organic carbon of the soil was positively correlated with leaf Mg, while it was negatively correlated with leaf S. The relationship between soil N, P, K, Mg, S and Mn were found to be positively correlated to their plant nutrient contents and were significant. The Mg was found to be positive and highly correlated with the leaf Mg and soil Fe was negatively correlated with leaf Mn. The soil Ca, Cu and Zn did not show any significant relationship with any of the leaf nutrients. A highly positive and significant correlation of leaf nutrient status with the nutrient status of surface depth indicates that, surface depth was contributing more towards nutrient uptake by the mango plant.

CONCLUSION

The present studies revealed that the mango orchard soil pH in Sirmour district was near neutral in reaction. The soils are in safe limits of electrical conductivity as the values were less than 0.8 dsm^{-1} . On the basis of nutrient index, it was concluded that the soil samples were medium in Cu, Zn and N whereas, high in P, K, Ca, Mg, S, Fe and Mn. The fertility status of the soil indicated that 100 per cent soils were high in P, K, Ca, Mg, S and Fe in the surface layers.

The soil pH had a significant relationship with soil N in the surface layer and negatively significant relationship with K in the sub-surface layers. The surface soil EC was negatively related to soil Cu in surface layer and sub-surface layers and positively correlated with K in sub-surface layer. Similarly, the organic carbon contents were highly correlated with N, P and K for both the soil layers. N, Mg and Mn in the surface while Mg and S in the sub-surface layers had a positive correlation with their respective leaf nutrient contents. The correlations for many parameters were, however, not significant and varied for the two soil depths, thus indicating a need to standardize the available nutrient extraction methods or the change in the critical limits suiting our conditions.

LITERATURE CITED

- A.O.A.C. 1970. Official and tentative methods of analysis. Association of official Analytical Chemists. William Star Wet glad, Washington.
- Amacher Michael C O'Neil, Katherine P Perry, Charles H. 2007. Soil vital signs: A new Soil Quality Index (SQI) for assessing forest soil health. Res. Pap. RMRS-RP-65WWW. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station p.12.
- Anderson C A and Albrigo G L. 1977. Seasonal changes in the relationship between macronutrients in orange leaves and soil analysis data in Florida. *Proceedings of International Society of Citric*. Vol.1.
- Anonymous. 2015a. National Horticultural Board Statistical Database, Gurgaon.
- Anonymous. 2001. Project report on soil test crop response. ISSS. New Delhi. 56p.
- Anonymous. 2015b. Units and critical limits of different parameters used for delineation. Himachal Pradesh Krishi Vishvavidyalaya, Palampur, Himachal Pradesh.
- Arnold SL, Doran JW, Schepers J, Wienhold B. 2005. Portable probes to measure electrical conductivity and soil quality in the field. *Communal Soil Science Plant Analysis* 36: 2271–2287.
- Arora CL and Takkar PN. 1988. Influence of soil characteristics on the forms and availability of sulphur in some entisols and inceptisols. *Journal of the Indian Society of Soil Science* 36: 496-499.
- Aso PJ and Bustos VN. 1981. Conditions relating Mg deficiency in citrus orchards of Tucuman. *Revista Industrial Y Agricola de Tucuman* 57: 9–13.
- Aso PJ and Dantur NC. 1970. Citrus nutrient deficiencies in Tucuman. *Revista Industrial y Agricola de Tucuman* 47: 10–61.
- Avasthe Y and Avasthe RK. 1995. Relationship between altitude and available nitrogen, phosphorus and potassium in some soils of Sikkim. *Journal of Hill Research* 8: 33–38.
- Avilan RL, Leal F and Meneses L. 1987. Root system distribution in sweet orange (*Citrus sinensis*) and grapefruit (*Citrus paradisi*) on sour orange (*Citrus aurantium*) in calcareous soils of the Lake Valencia basin. *Horticulture Abstracts* 57: 771.
- Awasthi RP, Bhutani VP, Kaith NS and Sharma JC. 1999. Mineral nutrient status of peach orchards in Sirmour district of Himachal Pradesh. *Indian Journal of Horticulture* 56: 194-200.
- Awasthi RP, Bhutani VP, Sharma JC and Kaith NS. 1998. Mineral nutrient status of apple orchards in Shimla district of Himachal Pradesh. *Indian Journal of Horticulture* 56: 194-200.

- Badhe NN, Naphade KT and Ballal DK. 1971. Status of available copper and manganese of soils from Bhadra district of Maharashtra. *Journal of Indian Society of Soil Science* 19: 175-178.
- Bala N and Sahu GC. 1993. Characterization and classification of soils on hill slope of middle Andaman Islands. *Journal of the Indian Society of Soil Science* 41: 133-137.
- Beridzen ZA. 1987. Some factors affecting mandarin growth and yield. *Subtropicheskie Kul'tury* 3: 76-82.
- Bhanawaria R, Kamariya PR and Yadav BL. 2011. Available micronutrient status and their relationship with soil properties of Mokala soil series of Rajasthan. *Journal of the Indian Society of Soil Science* 59: 392-396.
- Bhandari AR and Randhawa NS. 1985. Distribution of available micronutrients in soils of apple orchards in Himachal Pradesh. *Journal of the Indian Society of Soil Science* 33: 171-175.
- Bhandari AR and Tripathi BR. 1979. Soil testing in fertilizer recommendations. Department of Soil Science, *Technical Bulletin 10*, Department of Agriculture, Himachal Pradesh, Shimla.
- Bharambe PR, Shelke DK, Jadhav GS, Vaishnava VG and Oza SR. 2001. Management of salt affected vertisols with sub-surface drainage and crop residue incorporation under soybean wheat cropping system. *Journal of the Indian Society of Soil Science* 49: 24-29.
- Bhargava BS and Dhandar DG. 1987. Leaf sampling technique for pomegranate (*Punica granatum*). *Progress Horticulture* 19: 196-199.
- Bhargava BS and Raghupati HB. 1993. Analysis of plant materials for macro and micronutrients. In: *Method of Analysis of Soils, Plants, Waters and Fertilizers*. Tandon H L S (ed.), FDCO, New Delhi pp.49-82
- Bhattacharya A, Baruah U, Gangopadhyay SK and Kumar D. 1997. Characterization of some aquepts occurring in Assam valley. *Journal of the Indian Society of Soil Science* 45: 791-796.
- Bielorai S, Dasberg S, Erner Y and Brum M. 1988. The effect of saline irrigation water on Shamouti orange production. In: *Proceedings of the Sixth International Citrus Congress*, Vol. 2, Goren R and Mendel K (eds.), Rehovot, Israel: Balaban Publishers, Israel. 707-715p.
- Brady NC and Weil RR. 2002. *Nature and properties of soils*, 13th Ed. Prentice- Hall Inc., New Jersey, USA. 960p.
- Brady NS. 1996. *The nature and properties of soils*. 12th ed. Prentice Hall of India Pvt. Ltd, New Delhi, India.
- Brar JS. 1998. Fertility status of soils of Punjab and contribution of ground water towards plant nutrition. In: *Balance fertilization in Punjab agriculture* (M S Brar and S K Bansal, eds.). Department of soils, PAU, Ludhiana. 10p.

- Bredell GS and Conradie JH. 1975. Replanting of citrus: a survey of the chemical composition of old and new soil. *Citrus & Subtropical Fruit Journal* 496: 8–10.
- Campbell R. 2000. Reference sufficiency ranges for plant analysis in the southern region of the united states. *Southern Cooperative Series Bulletin*. 79-80p.
- Cannel GH, Bingham FT and Garber MT. 1960. Effects of irrigation and phosphorous on vegetative growth and nutrient composition of tomato leaves. *Soil Science* 89: 53-60.
- Cerda AM, Nieves MA and Guillen MG. 1990. Salt tolerance of lemon trees as affected by rootstock. *Irrigation Science* 11: 245–249.
- Chadha KL, Samra JS and Thakur RS. 1980. Standardization of leaf sampling technique for mineral composition of leaves of mango cultivar Chausa. *Scientia Horticulture* 13: 323-329.
- Chahill BS, Dhatt AS, Singh Ragbir, Dhillon DS and Singh R. 1991. Studies on the leaf nutrients standards in kinnow. *Indian Journal of Horticulture* 48: 315-320.
- Chand M, Benbi DK and Benipal DS. 2006. Fertilizer recommendations based on soil tests for yield targets of mustard and rapeseed and their validations under farmer's field conditions in Punjab. *Journal of the Indian Society of Soil Science* 54: 316-321.
- Chapman HD. 1960. Leaf and soil analysis in citrus orchards. *Calif. Agric. Exp. Sta. Manual* 25p.
- Chapman HD. 1964. Suggested foliar sampling and handling techniques for determining the nutrient status of some field, horticultural and plantation crops. *Indian Journal of Horticulture* 21: 97-116.
- Chattopadhyay T, Sahu AK, Singh RS and Shyampura RL. 1996. Available micronutrient status in the soils of Vindhyan scraplands of Rajasthan in relation to soil characteristics. *Journal of the Indian Society of Soil Science* 44: 678-681.
- Chaudhary HP and Das SK. 1990. Nutrients status in relation to intensity of erosion in ravines of Yamuna. *Journal of the Indian Society of Soil Science* 38: 126-129.
- Chaudhary SK, Singh K, Tripathi D and Bhandari AR. 2005. Morphology, genesis and classification of soils from two important land uses in outer Himalayas. *Journal of the Indian Society of Soil Science* 53(3): 394-398.
- Chavan SD and Patil VK. 1980. Standardization of leaf sampling technique in sapota (*Achras sapota* Syn). *Indian Journal of Horticulture* 37: 239-241.
- Chen CR, Xu ZH, Zhang SL and Keay P. 2005. Soluble organic nitrogen pools in forest soils of subtropical Australia. *Plant and Soil* 277: 285-297.
- Cheng QM and Zeng KY. 1991. Hongguang, the best strain of Nanfeng Guangju. *China Citrus* 20: 17–23.
- Chesnin Leon and Yien CH. 1950. Turbidimetric determination of available sulphates. *Soil Science Society of America Proceedings* 15: 149-151.

- Dasberg S, Bielorai H, Haimowitz A and Erner Y. 1991. The effect of saline irrigation waters on Shamouti orange trees. *Irrigation Science* 12: 205–211.
- Das HC, Srivastava AK, Ram L and Singh S. 1998. Flowering behavior of Nagpur mandarin (*Citrus reticulata*) as affected by vertical variation in physico-chemical composition of black soils. *Indian Journal of Agricultural Science* 68: 692–694.
- De Pascal, Magyio A, Ruggiero C and Barbieri G. 2003. Growth, water relations, ion content of field-grown Celery (*Apium graveolens* L. Var. Dulce (Mill.) Pers), under Saline irrigation. *Journal of American Society of Horticulture Science* 128: 128-135.
- Devi SGM and Kumar AKS. 2010. Characterization and classification of coffee growing soils of Karnataka. *Journal of the Indian Society of Soil Science* 58: 125-131.
- Devrani HB and Sant Ram. 1980. Effect of age and flush on the mineral content of mango leaves. *Indian Journal of Horticulture* 37: 35-40.
- Dhale SA and Prasad J. 2009. Characterization and classification of sweet orange growing soils of Jalna district of Maharashtra. *Journal of the Indian Society of Soil Science* 57: 11-17.
- Dhandar DG and Bhargava BS. 1993. Leaf sampling technique for nutritional diagnosis in custard apple. *Indian Journal of Horticulture* 50: 1-4.
- Dhillon WS and Dhatt AS. 1988. Nutrients status and productivity of kinnow orchards in Ferozepur district. *Punjab Journal of Horticulture* 28: 7-13.
- Ding S, Zhang X, Bao Z and Liang M. 1990. *Citrus Ichangensis* in Yunnan. In: Proceedings of the International Citrus Symposium. Bangyan H and Qian Y (eds.), Guanzhou, China, International Academic Publishers 170–181p.
- Dongale JM. 1993. Depth distribution of different forms of phosphorus in lateritic soils of coastal region. *Journal of the Indian Society of Soil Science* 41: 62-66.
- Eck HV and Unger PW. 1985. Soil profile modification for increasing crop production. *Advances in Soil Sciences* 1: 65–83.
- Egashira K, Nakashima S and Fujiyama M. 1990. Quantification analysis of the contribution of environment, soil and management factors to crop yields—case study of the yield of rice, potato and orange in Nagasaki prefecture. *Science Bulletin, Faculty, Agriculture, Kyushu University Fukuoka, Japan* 45: 9–21.
- Embleton TW, Jones WW, Labanauskas CK and Platt RG. 1971. Leaf analysis and phosphorus fertilization of oranges. *Citrog* 56: 101-124.
- FAI. 1977. *Hand book of fertilizer usage*, 54th ed., The Fertilizer Association of India, New Delhi.
- Fidalski J and Auler PAM. 1997. Nutritional survey of orange plantations in northwest Parana. *Arquivos de Biologia e Tecnologia* 40: 443–451.

- Fidalski J, Pavan MA, Auler PA, Jacomino AP. 1999a. Produção de frutos de laranja e teores de nutrientes nas folhas e no solo, em Latossolo Vermelho-Escuro do noroeste do Paraná. *R. Bras. Ci. Solo* 23: 273-279.
- Gangopadhyay SK, Das PK, Mukhopadhyay N, Nath S and Banerjee SK. 1990. Altitude pattern of soil characteristics under forest vegetation in eastern region. *Journal of the Indian Society of Soil Science* 38: 93-99.
- Gangopadhyay SK, Walia CS, Chamuah GS and Baruah U. 1998. Rice growing soils of upper Brahmaputra valley of Assam-their characteristics and suitability. *Journal of the Indian Society of Soil Science* 46: 103-109.
- Garcia C, Hernander T, Costa F. 1994. Microbial activity in soils under Mediterranean environmental conditions. *Soil Biology and Biochemistry* 26: 1185-1191.
- Ghosh AB and Hasan R. 1976. Available potassium status of Indian soils. *Bulletin of Indian Society of Soil Science* 10: 1-5.
- Ghosh AB and Hasan R. 1979. Available phosphorus status of Indian soils. *Bulletin of Indian Society of Soil Science* 12: 1-4.
- Ghosh AB and Hasan R. 1980. Available nitrogen status of Indian soils. *Fertilizer News* 25 11: 19-21.
- Ghosh SP and Singh RB. 1993. Citrus in South Asia. Bangkok: FAO Regional Office Bangkok, Thailand.
- Grewal JS, Bhumbra DR and Randhawa NS. 1969. Available micronutrient status of Punjab, Haryana and Himachal soils. *Journal of Indian Society of Soil Science* 17: 27-31.
- Gupta RD and Tripathi BR. 1989. Morphological, physico-chemical, mineralogical properties and pedogenesis of some rice growing soils profiles occurring in Kangra district of Himachal Pradesh. *Oryza* 26: 263-272.
- Gupta RD and Tripathi BR. 1996. Mineralogy, genesis and classification of soils of North West Himalayas developed on different parent materials and variable topography. *Journal of the Indian Society of Soil Science* 44: 705-711.
- Gururani AK and Singh R. 1983. Variation in mineral composition of leaves from different flushes of kinnow mandarin under Tarai condition. *Punjab Journal of Horticulture* 28: 141-147.
- Hernando V. 1969. Soil and leaf analysis of orange tree orchards on several types of soils in Valencia province. In: Proceedings of the International Citrus Symposium. Chapman H D (ed), Florida, USA: International Society of Citriculture, 3: 1673-1688.
- Hettelingh JP, Slootweg J and Posch M. 2008. Critical load, dynamic modelling and impact assessment in Europe: CCE status Report 2008. The Netherlands, Netherlands Environmental Assessment Agency, 44-50p.

- Hochmuth GJ and Hanlon EA. 1995. Commercial vegetable crop nutrient requirements in Florida. Gainesville (FL): University of Florida Cooperative Extension Service. Special Publication SP 177.
- Hodgson J F. 1963. Chemistry of the micronutrients in soils. *Advances in Agronomy* 15: 119-149.
- Jackson M L. 1967. *Soil Chemical Analysis*. Oxford and IBH Publishing House, Bombay. pp 38.
- Jackson M L. 1973. *Soil Chemical Analysis*. Prentice Hall of India Pvt. Ltd., New Delhi.
- Jackson M L. 2005. *Soil Chemical Analysis*. Prentice Hall of India Pvt. Ltd., New Delhi.
- Jalali VK, Talib AR and Takkar PN. 1989. Distribution of micronutrients in some benchmark soils of Kashmir at different altitudes. *Journal of the Indian Society of Soil Science* 37: 465-469.
- Jha SN, Mishra LK and Jha NK. 1988. Studies on distribution of some nutrient elements and solutes in calcareous soils of Bihar. *Journal of the Indian Society of Soil Science* 36: 421-426.
- Kaistha BP and Gupta RD. 1993. Morphology, mineralogy, genesis and classification of soils of the sub-humid temperate high lands of the central Himalayas. *Journal of the Indian Society of Soil Science* 41: 120-124.
- Kaistha BP and Gupta RD. 1994. Morphology and characteristics of a few Entisols and Inceptisols of North Western Himalayan region. *Journal of the Indian Society of Soil Science* 42: 100-104.
- Kaistha BP, Sood RD and Kanwar BS. 1990. Distribution of nitrogen in some forest soil profiles of north western Himalayan region. *Journal of the Indian Society of Soil Science* 38: 15-20.
- Katyal JC and Aggarwal SC. 1982. Distribution of total and available micro-nutrient cations in some mulberry growing soils of Krishnarajpet, Karnattaka. *Fertilizer News* 27: 66-86.
- Kaul GL. 1968. Relationships between soil analysis and leaf analysis of apple orchards in Kullu valley. M.Sc. Thesis, Punjab Agriculture University, Ludhiana.
- Khajuria Neetan. 2010. Impact of industrialization on water quality and soil health in Baddi-Barotiwala-Nalagarh industrial hubs of Himachal Pradesh. Ph D. Thesis, Department of Soil Science, UHF, Nauni, Solan. 146p.
- Khan ZH, Mazumdar AR, Hussain MS and Mohiuddin ASM. 1997. Total and DTPA-extractable Fe, Mn, Cu and Zn content in some soils of Bangladesh. *Journal of the Indian Society of Soil Science* 45: 485-489.
- Ko KD and Kim SK. 1987. Chemical properties of soil and leaf mineral contents in Cheju citrus orchards. *Journal of Korean Society of Horticulture Science* 28: 45-52.
- Kong-Tau T. 1986. Physical properties of some main soil groups of Vietnam. *Soviet Soil Science* 18(4): 111-117.

- Kotur KV. 2013. Fertiliser management of vegetable and seed purpose Okra with emphasis on yield, N and P fertiliser use efficiency and seed quality. *Indian journal of fertilisers* 9: 70-74.
- Kumar AHP and Prasad J. 2010. Some typical sugarcane growing soils of Ahemadnagar district of Maharashtra: their characterization, classification and nutritional status of soils and plants. *Journal of the Indian Society of Soil Science* 58: 257-266.
- Kumar K, Adak T, Singha A, Shukla SK and Singh VK. 2012. Appraisal on soil fertility, leaf nutrient concentration and yield of mango at Malihabad region, Uttar-Pradesh. *Current Advances in Agricultural Sciences* 4: 13-19.
- Kumar P and Rehalia AS. 2007. Standardization of micronutrients ranges in mango by orchard surveys. *The Asian Journal of Horticulture* 2: 218-221.
- Kumar P and Verma TS. 2005. Characterization and classification of some rice growing soils of Palam valley of Himachal Pradesh. *Agropedology* 15: 80-85.
- Kumar P and Verma TS. 2005. Characterization and classification of some rice growing soils of Palam valley of Himachal Pradesh. *Agropedology* 15: 80-85.
- Labanauskas CK, Jones WW and Embleton TW. 1959. Seasonal changes in concentration of micro-nutrients (zinc, copper, boron, Manganese and Iron) in leaves of Washington Navel orange. *American Society of Horticultural Science* 74: 300-306.
- Lahiri T and Chakravarti SK. 1989. Characteristics of some soils of Sikkim at various altitudes. *Journal of the Indian Society of Soil Science* 37: 451-454.
- Larson WE and Pierce FJ. 1991. Conservation and enhancement of soil quality. In: Proceedings of International Workshop on Evaluation of Sustainable Land and Management in the Developing World. 2: 175-203.
- Laxminarayan K. 2006. Evaluation of available nitrogen indices for rice in soils of Mizoram. *Journal of the Indian Society of Soil Science* 54(2): 322-326.
- Li JL, Li XX, Peng JC and Zhuang GQ. 1999. Effect of five mineral elements on nutritional status of Navel orange tree. *Journal of Hunan Agriculture University* 25: 36-39.
- Lindsay WH and Norvell WA. 1978. Development of DTPA soil test for Zn, Fe, Mn and Cu. *Soil Science Society of American Journal* 42: 420-428.
- Lombion LG. 1979. Evaluation of magnesium supplying power of the Nigerian Savannah soils. *Soil Plant Nutrition* 25: 477-492.
- Lyon CB, Beeson KC and Ellis GH. 1943. Effects of micro-nutrient deficiencies on growth and vitamin content of the tomato. *Bot. Gaz.* 104: 495-514.
- Mahajan A. 2001. Characterization of Balh valley soils of District Mandi. M Sc Thesis, Department of Soil Science, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur, India. 133p.

- Malavolta E, Violante Netto A. 1989. Nutriçãomineral, calagem, gessagem e adubação dos citros. Piracicaba: POTAFOS 153p.
- Malewar GU, Varade SB and Jadhav NS. 1983. Evaluation of nutritional status of citrus orchards of Marathwada region (Maharashtra state) by leaf and soil analysis. In: *Proceedings, International Citrus Symposium*, Bangalore, India: Indian Institute of Horticultural Research 14–21p.
- Mandal AK, Nath S, Gupta SK and Banerjee SK. 1990. Characteristics and nutritional status of soils of middle hill and upper hill forest of eastern Himalayas. *Journal of the Indian Society of Soil Science* 38: 100-106.
- Manna MC, Swarup A, Wanjari RH, Ravankar HN, Mishra B, Saha MN, Singh YV, Sahi DK and Sarap PA. 2005. Long-term effect of fertilizer and manure application on soil organic carbon storage, soil quality and yield sustainability under sub-humid and semi-arid tropical India. *Field Crops Research* 93: 264–280.
- Medvedev VV. 1990. Variability of the optimal soil density and its causes. *Soviet Soil Science* 22: 65–75.
- Mengel K and Kirkby EA. 1987. Principles of plant nutrition. Panima publishing company: New Delhi, India. 687p.
- Merwin HD and Peach M. 1951. Exchangeability of soils potassium in the silt and clay fractions as influenced by the nature of the complimentary exchangeable cations. *Soil Science Society of American Proceedings* 15: 125-128.
- Mesfin A, 1998. Nature and management of Ethiopian soils. Alemaya University of Agriculture, Ethiopia. 272p.
- Milad S, Bakhati HK, El-Hakim M and Moutafa FB. 1975. The effect of different soil conditions upon citrus growth. *Agriculture Research Review* 53: 31–40.
- Minhas RS, Minhas HK and Verma SD. 1997. Soil characterization in relation to forest vegetation in the wet temperate zone of Himachal Pradesh. *Journal of the Indian Society of Soil Science* 45: 146-151.
- Mishra DK, Das RP and Mitra GN. 1990. Forms of sulphur in some soils of Orissa in relation to relevant soil properties. *Journal of the Indian Society of Soil Science* 36: 61-69.
- Mondol AK, Sharma V, Jalali VK, Arora S, Wali P and Kher D. 2007. Distribution and relationship of macro and micro nutrients in soils of Chatthar of Jammu. *Journal of Research, Sher-E-Kashmir University of Agriculture Science and Tehnology* 6: 234-242.
- Morgan ML. 1937. Universal soil testing system. *Connecticut State Agriculture Experiment Bulletin* 292: 129-159.
- Motsara MR. 2002. Available nitrogen, phosphorus and potassium status of Indian soils as depicted by soil fertility maps. *Fertilizer News* 47: 15-21.
- Nair KM and Chamuah GS. 1988. Characteristics and classification of some pine forest soils of Meghalaya. *Journal of the Indian Society of Soil Science* 36: 142-145.

- Najar GR, Akhtar F, Singh SR and Wani JA. 2009. Characterization and classification of some apple growing soils of Kashmir. *Journal of the Indian Society of Soil Science* 57: 81-84.
- Nazif W, Sajida P and Iftikhar S. 2006. Status of micronutrients in soils of District Bhimber (Azad Jammu and Kashmir). *Journal of Agricultural and Biological Science* 1: 35-38.
- Nieves M, Garcia A and Cerda A. 1991a. Salt tolerance of two lemon scions measured by leaf chloride and sodium accumulation. *Journal of Plant Nutrition* 14: 623–636.
- Nieves M, Garcia A and Cerda A. 1991b. Effect of salinity and rootstock on lemon fruit quality. *Journal of Horticulture Science* 66: 127–130.
- Nilangekar RG and Patil VK. 1982. Soil factors as related to citrus decline. *Journal of Indian Society of Soil Science* 30: 213–215.
- Nunez-Moreno JH and Valdez-Gascon B. 1994. Effect of soil conditions on orange tree. *Communications in Soil Science & Plant Analysis* 25: 1747-1753.
- Obreza TA. 1973. Program fertilization for establishment of orange trees. *Agriculture Production* 6: 546–552
- Olsen SR, Cole CV, Watanable FS and Dean LA. 1954. Estimation of available phosphorous in soil by extraction with sodium bicarbonate. *USDA Circular* 939: 1-19.
- Pandey IC. 1966. An attempt to study the relationship between Chail's and Shimla state series in Kandaghat area of Shimla district, presented at first Himalayan geology seminar held at Punjab University, Chandigarh. 141-155p.
- Pandey SP, Singh RS and Mishra SK. 2000. Availability of phosphorus and sulphur in Inceptisols of central Uttar Pradesh. *Journal of the Indian Society of Soil Science* 48: 118-121.
- Patel KS, Chikhlekar S, Ramteke S, Sahu BL, Dahariya NS and Sharma R. 2015. Micronutrient status in soil of central India. *American Journal of Plant Sciences* 6: 3025-3037.
- Patgiri DK and Datta K. 1993. Forms and distribution of phosphorus in some tea growing soils of Assam. *Journal of the Indian Society of Soil Science* 41: 346-348.
- Patil GD, Khedkar VR, Tathe AS and Deshpande AN. 2008. Characterization and classification of soils of agriculture collegefarm, Pune. *Journal of Maharashtra Agriculture University* 33: 143-148.
- Patil KD, Meisheri MB, Dabke DJ and Bagade DS. 2003. Distribution of DTPA-extractable Zinc, Copper, Iron and Manganese content in soils of Konkan region. *Journal of Soils and Crops* 13: 85-90.
- Pavan MA and Wutscher HK. 1993. Accumulation of nutrients at the surface of roots of blight affected orange trees. *Communications in Soil Science & Plant Analysis* 24: 979–987.

- Pikul JL and Aase JK. 1994. Infiltration and soil properties as affected by annual cropping in the Northern great plains. *Soil Science Society of America* 87: 656-662.
- Powar SL and Mehta VB. 1999. Characterization of soils of Konkan coast. *Journal of the Indian Society of Soil Science* 47: 334-337.
- Prahlad Kumar and Pandey RM. 1980. Effect of leaf age and its position on dry matter accumulation and mineral composition of Guava (*Psidium guajava* L.) leaves. *Indian Journal of Horticulture* 3: 229-234.
- Quaggio JA, Teofilo Sobrinho J and Dechen AR. 1992. Magnesium influence on fruit yield and quality of Valencia sweet orange on Rangpur lime. In: Proceedings of the International Society of Citriculture. Tribulato E, Gentile A and Refergiato G (eds.), Acireale, Italy: International Society of Citriculture 2: 633-637.
- Rai MM, Pal AR, Chimania BP, Shitoley DB and Vakil P. 1972. Available micronutrient status of black soils of Madhya Pradesh. *Journal of Indian Society of Soil Science* 20: 129-134.
- Raina JN. 1988. Physico-chemical properties and available micronutrient status of citrus growing soils of Ponta valley in Himachal Pradesh. *Himachal Journal of Agricultural Research* 14: 44-49.
- Rajeshwar M, Rao Sujinich, Balaguraviash D and Khan Aariff MA. 2009. Distribution of available micronutrients in soils of Garikapadu of Krishna district of Andhra Pradesh. *Journal of the Indian Society of Soil Science* 57: 210-213.
- Rajkumar, Nayyar VK, Sidhu GS and Deshmukh SN. 1990. Distribution of available micronutrient cations in some dominant soil series in different physiographic units of Bundelkhand region of Madhya Pradesh. *Journal of the Indian Society of Soil Science* 38(2): 410-415.
- Ramamoorthy B and Bajaj JC. 1969. Available nitrogen, phosphorus and potassium status of Indian soils. *Fertilizer News* 14: 25-36.
- Ramana Murthy J and Srivastava P. 1994. Soil fertility status in relation to terrace management at Majhera Farm in lower Shivaliks. *Journal of the Indian Society of Soil Science* 42: 150-152.
- Randhawa GS and Kar PL. 1967. Seasonal changes in the mineral composition of non-bearing and bearing shoot of mandarin. *Indian Journal of Horticulture* 24: 38-46.
- Rattan RK, Datta SP and Katyal JC. 2008. Micronutrient management: research achievements and future challenges. *Indian Journal of Fertilizers* 4: 93-118.
- Ravishankar H, Kumar K, Singha A and Adak T. 2010. Integrated nutrient management in mango and guava. *Indian journal of Horticulture* 47: 180-185.
- Reddy YTN, Kurian RM, Sujatha MT and Srinivas M. 2003. Leaf and soil nutrient status in relation to yield of mango. *Indian Journal of Horticulture* 60: 121-126.

- Rehalia AS and Nijjar GS. 1986. Leaf sampling for mineral composition of sub tropical peach (*Prunus persica* Batsch) cv. Flordasun. *Punjab Journal of Horticulture* 26: 61-66.
- Rengaswamy P, Olson KA and Kirby JM. 1992. Sub soil constraints to root growth and high soil water and nutrient use by plants. In: Proceedings of National Workshop. Tanunda, Australia: Department of Primary Industries, South Australia.
- Rengel Z. 2015. Availability of Mn, Zn and Fe in the rhizosphere. *Journal of Soil Science and Plant Nutrition* 15: 397-409.
- Reuther W and Smith PF. 1955. Leaf analysis as a guide to the nutritional status of orchard tree. *Plant analysis and fertilizer problems* 166-180p.
- Reuther W, Batchlor HJ and Weller HJ. 1962. Citrus industry. Vol. II. University of California Press, Berkley, California.
- Richard LA. 1954. Diagnosis and improvement of saline and alkali soils. USDA Handbook No. 60 US Department of Agriculture, Washington D.C. (USA).
- Ruhal DS and Paliwal KV. 1980. Soil properties affecting the availability of sulphur in soils of Rajasthan. *Journal of the Indian Society of Soil Science* 75: 1036-1040.
- Sahoo AK, Sarkar D, Baruah U and Butte PS. 2010. Characterization, classification and evaluation of soils of Longhol hill, Manipur for rational land use planning. *Journal of the Indian Society of Soil Science* 58: 1-6.
- Sahu GC and Patnaik SN. 1990. Influence of lime and organic matter in pH and ion exchange phenomenon of some Alfisols. *Journal of the Indian Society of Soil Science* 38: 389-393.
- Sakal R, Singh AP, Singh BP, Singh RB, Singh SP and Jha SN. 1986. Availability of zinc, iron, copper and manganese in sub Himalayan Hill and forest soils as influenced by certain soil properties. *Journal of the Indian Society of Soil Science* 34:191-193.
- Samanta A, Chatterjee AK, Meti PK and Mandal B. 2002. Status of total and available iron and zinc in soils of West Bengal under continous cultivation of mulberry. *Journal of the Indian Society of Soil Science* 50: 35-42.
- Samra JS, Chadha KL and Thakur RS. 1979. Comparison of some mango cultivars in terms of their micronutrient status in fruiting and non-fruiting terminals. *Indian Journal of Horticulture* 184-187.
- Sanchez PA. 1976. Properties and management of soils in the tropics. John Wiley and Sons, Inc., New York, USA. 618p.
- Sangwan BS and Singh K. 1993. Vertical distribution of Zn, Cu, Mn and Fe in the semi arid soils of Haryana and their relationships with soil properties. *Journal of the Indian Society of Soil Science* 41: 463-467.
- Sanyal D and Mitra SK. 1990. Standardization of leaf sampling technique for mineral composition of litchi cv. Bombai. *Indian Journal of Horticulture* 47: 371-375.

- Sarkar D and Sahoo AK. 2000. Aquepts of Indo-Gangetic plain of Bihar and their suitability for some major crops. *Journal of the Indian Society of Soil Science* 48: 561-566.
- Sarma VAK, Krishna P and Budihal SL. 1987. *Soil Resource Mapping of Different States in India- A Laboratory Manual*. National Bureau of Soil Survey and Land Use Planning, Nagpur. 49p.
- Sauchelli V. 1969. Trace elements in agriculture. Rainhold publishing company, New York 80p.
- Shankhyan CG. 1972. Studies on physico-chemical properties of the representative profiles under tomato growing areas of Saproon valley (Himachal Pradesh), M Sc Thesis, Department of Soil Science, College of Agriculture, H.P. University, Shimla, India. 125 p.
- Sharma BK and Singh N. 2001. Characteristics and properties of soils under two dominant land use systems in western Rajasthan. *Journal of Indian Society of Soil Science* 49: 373–377.
- Sharma JC and Choudhary SK. 2007. Vertical distribution of micronutrient cations in relation to soil characteristics in lower Shivaliks of Solan districts in North–West Himalayas. *Journal of the Indian Society of Soil Science* 55: 40-44.
- Sharma JC. 1988. Nutritional survey of apple orchards in Sirmour district of Himachal Pradesh. M.Sc. Thesis, University of Horticulture and Forestry, Solan, India.
- Sharma PD, Acharya CL, Sharma SP, Sood RK and Sharma VK. 1998. Soil and water resource management strategies for sustainable land productivity in three watersheds of Kangra district (DST project). Department of Soil Science, Himachal Pradesh Krishi Vishvavidyalaya, Palampur. 86p.
- Sharma PK, Sharma SP and Jain PK. 2001. Nutrient mining in different agro-climatic zones of Himachal Pradesh. *Fertilizer News* 46: 69-73.
- Sharma U and Bhandari AR. 1992. Survey of the nutrient status of apple orchards in Himachal Pradesh. *Indian Journal of Horticulture* 49: 234-241.
- Sharma U. 1990. Nutritional survey of apple orchards in Mandi district of Himachal Pradesh. M.Sc. dissertation, University of Horticulture and Forestry, Solan, India.
- Sharma U. 1994. Studies on the nutrient status in the soils and trees of apple orchards in Chamba district of Himachal Pradesh Ph.D. dissertation, UHF, Solan India.
- Sharma V and Kanwar BB. 2010. Copper status and its relation with soil properties in pea growing soils of high hills dry temperate zone of Himachal Pradesh. *Indian Journal of Agricultural Research* 44: 32-37.
- Sharma V and Kanwar BB. 2012. Micronutrients availability in pea growing soils of dry temperate zone of Himachal Pradesh. *Agriculture Science Digest* 32: 301-305.
- Sharma V and Kanwar BB. 2011. Manganese status and its relation with soil properties in pea growing soils of high hills dry temperate zone of Himachal Pradesh. *Journal of Soils and Crops* 17: 201-210.

- Sharma VK and Kumar A. 2003. Characterization and classification of the soils of upper Moul khad catchment in wet temperate zone of Himachal Pradesh. *Agropedology* 13: 39-41.
- Sharma VK, Kaistha BP, Dubey YP and Sharma RP. 2002. Soil fertility ratings in Fatehpur block of Kangra district of Himachal Pradesh for growing medicinal and aromatic plants. *Himachal Journal of Agricultural Research* 28: 20-25.
- Shawky I, Desouky I, El-Tomi A and Mohamed MA. 1980. Effect of pH on the growth and mineral content of some rootstock seedlings. *Egyptian Journal of Horticulture* 7: 19-31.
- Shekhar C. 2009. Status and distribution of magnesium in acidic soils of North-Western Himalayas. M.Sc. Thesis, Department of Soil Science. CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur, India, 59p.
- Shetty YS, Nagamma MS, Kumar D and Jayaprakash. 2008. Fertility status in arecanut garden soils of Karnataka. *Karnataka Journal of Agriculture Sciences* 21: 503-506.
- Shilpashree YP, Narayana J, Kumar A, Talegedi D, Shetty VY and Satish C. 2011. Nutrient status in arecanut garden soils of Shimoga and Bhadravathi Taluk. *Journal of Plant Archives* 11: 429-430.
- Shishov LL and Kapshuk MP. 1984. Soil conditions on irrigated citrus plantations in the Libyan arid zone. *Problems of Desert Development* 1: 39-45.
- Singh B and Raman SS. 1982. Distribution of nutrients in soil profile under pines of North East Himalaya. *Journal of the Indian Society of Soil Science* 30: 320-325.
- Singh K, Bhandari AR and Tomar KP. 1991. Morphology, genesis and classification of some soils of North-West Himalayas. *Journal of the Indian Society of Soil Science* 39: 139-146.
- Singh K, Goyal VP and Singh M. 1990. Distribution of micronutrient cations in semi-arid alluvial soil profiles. *Journal of the Indian Society of Soil Science* 38: 736-737.
- Singh MV. 2001. Evaluation of current micronutrient stocks in different agro-ecological zones India for sustainable crop production in India. *Fertilizer News* 42: 25-42.
- Singh MV. 2008. *Micro and secondary nutrients and pollutant elements research in India*. All India coordinated rainfed project. Indian Society of Soil Science, Bhopal, 1-77p.
- Singh MV. 2009. Micronutrient nutritional problems in soils of India and improvement for human and animal health. *Indian Journal of Fertilizers* 5: 11-21.
- Singh N. 1987. Leaf nutrient status of apple, grape and almond orchards of Kinnaur district of Himachal Pradesh and its relationship with the physico-chemical characteristics of the soils. Ph.D. dissertation, Himachal Pradesh Krishi Vishvavidyalaya, Palampur, India.
- Singh OP and Datta B. 1988. Organic carbon and nitrogen status of some soils of Mizoram occurring at different altitudes. *Journal of the Indian Society of Soil Science* 36: 414-420.
- Singh RR and Choudhary SN. 1990. Soil copper status of the calcareous belt of Bihar. *Journal of the Indian Society of Soil Science* 38: 317-318.

- Singh SP, Gupta RA and Singh HN. 2005. Distribution of micronutrient cations in some soils of Kumaon region of Uttaranchal. *Agropedology* 15: 117-119.
- Smith PF. 1966. Leaf analysis in citrus. In: Temperate to Tropical Fruit Nutrition. Chap. 8. Childera N F (ed.) Horticultural Publications, New Brun-Swick, N.J.
- Somasundaram J, Singh RK, Parandiyal AK and Parasd SN. 2009. Micronutrient status of soils under different land use system in Chambal ravines. *Journal of the Indian Society of Soil Science* 57 (3): 307-312.
- Soni S L and Randhawa G S. 1974. Seasonal variations in concentration of minerals in twigs of different growth flushes in lemon. *Indian Journal of Horticulture* 31: 321-322.
- Sood A, Sharma PK, Tur NS and Nayyar VK. 2009. Micronutrient status and their spatial variability in soils of Muktsar district of Punjab—a GIS approach. *Journal of the Indian Society of Soil Science* 57: 300-306.
- Sood RD, Kaistha BP and Bhargawa M. 1991. Distribution of organic phosphorus and its fractions in relation to soil properties in sub-humid and sub-tropical zone of Himachal Pradesh. *Journal of the Indian Society of Soil Science* 39: 569-572.
- Srivasta AK and Kholi RR. 1997. Soil suitability criteria for citrus - An Appraisal. *Agricultural Reviews* 18: 134-146.
- Srivastava AK and Singh S. 2003. Diagnostics of citrus nutrition. In: Citrus Nutrition, Lucknow, India: International Book Distribution Company 237–285p.
- Srivastava AK and Singh S. 2004. Soil and plant nutritional constraints contributing to citrus decline in Marathawada region, India. *Communications in Soil Science & Plant Analysis* 35: 2537–2550.
- Srivastava AK and Singh S. 2005. Zinc nutrition, a global concern for sustainable citrus production. *Journal of Sustainable Agriculture* 25: 5–42.
- Srivastava AK and Singh Shyam. 1998. Fertilizer use efficiency in citrus, Tech. Bull. No. I. National Research Centre for citrus, Nagpur 1-66p.
- Srivastava AK, Lallan Ram, Huchche AD, Kholi RR and Das HC. 1994. Standardization of leaf sampling technique in Nagpur mandarin under sub- humid tropical climate. *Indian Journal of Horticulture* 51: 32-35.
- Stino RP, Abd El-Wahed AM, Habashey SA and Kelani RA. 2011. Productivity and fruit quality of three mango cultivars in relation to foliar sprays of Ca, Zn, B and K. *Journal of the Agricultural Science and Ornamental Plants* 3: 91-98.
- Subbiah BV and Asija GL. 1956. Rapid method for estimation of available nitrogen in soils. *Current Science* 25: 259-260.
- Takkar PN and Nayyar UR. 1981. Preliminary field observations of manganese deficiency in wheat and berseem. *Fertilizer News* 26: 22-23.

- Takkar PN. 1996. Micronutrient research and sustainable agricultural productivity in India. *Journal of the Indian Society of Soil Science* 44: 562-581.
- Talukdar MC, Basumatary A and Dutta SK. 2009. Status of DTPA-extractable cationic micronutrients in soils under rice and sugarcane ecosystem of Golaghat district in Assam. *Journal of the Indian Society of Soil Science* 57: 313-316.
- Tandon HLS. 1989. Secondary and Micronutrient Recommendation for Soils and Crops. A Guide book. Fertilizer Development and Consultation Organization, New Delhi. 22p.
- Tandon HLS. 2004. *Nutrient deficiencies in Indian soils*. In: Fertilizers in Indian agriculture from 20th to 21st century. Fertilizer Development and Consultation Organization, New Delhi. 45p.
- Thakur NR and Bhandari AR. 1986. Available nutrient elements status of soils of a temperate vegetable seed producing valley of Himachal Pradesh. *Journal of the Indian Society of Soil Science* 34: 428-430.
- Thakur Noop Ram. 1979. Nutritional status of cauliflower seed producing area of Himachal Pradesh. M.sc. Thesis. Department of Soil Science, CSK Himachal Pradesh Krishi Vishvadiyalaya, Palampur, India. 63p.
- Thakur PC, Rajoo RK and Dwivedi P. 1971. Nutrient indices, fertilizer requirements and recommendation for Mandi soils. *Himachal Journal of Agricultural Research* 1: 61-64.
- Tisdale SL, Nelson WL, Beaton JD and Havlin JL. 1995. Soil fertility and fertilizer, 5th Ed. Prentice-Hall of India, New Delhi. 684p.
- Tiwary JR and Mishra BB. 1990. Distribution of micronutrients in tal land soils (Udic chromousterts) of Bihar. *Journal of the Indian Society of Soil Science* 38: 319-321.
- Tripathi D and Singh K. 1992. Vertical distribution of sulphur in representative soil groups of Himachal Pradesh. *Journal of the Indian Society of Soil Science* 40: 447-553.
- Tripathi D, Patial KS, Verma JR and Singh K. 2007. Soil fertility of Kiar-Nagali micro watershed in Solan district of Himachal Pradesh. *Journal of the Indian Society of Soil Science* 55: 222-223.
- Tripathi D, Singh K and Upadhyay GP. 1994. Distribution of micronutrients in some representative soil profiles of Himachal Pradesh. *Journal of the Indian Society of Soil Science* 42: 143-145.
- Tripathi D, Upadhyay GP, Bhandari AR and Sharma U. 1992. Potassium distribution in some orchid soils in Mandi district of Himachal Pradesh. *Journal of Potassium Research* 8: 264-267.
- Trivedi SK, Tomar RAS, Tomar PS and Gupta N. 2010. Vertical distribution of different forms of phosphorus in alluvial soils of grid region of Madhya Pradesh. *Journal of the Indian Society of Soil Science* 58: 86-90.

- Tundup P and Akbar A. 2014. Distribution of micronutrient cations (Zn, Cu, Mn, Fe) and their relationship with soil properties of saffron growing soils of district Kishtwar in J&K. *An Asian Journal of Soil Science* 9: 59-62.
- Vadivelu S and Banyopadhyay AK. 1995. Distribution of DTPA-extractable Fe, Mn, Cu and Zn in the soils of Minicoy island, Lakshadweep. *Journal of the Indian Society of Soil Science* 43: 133-134.
- Vara Prasad Rao AP, Naidu MYS, Ramavatharam N and Rama Rao G. 2008. Characterization, classification and evaluation of soils on different landforms in Ramachandrapuram mandal of Chittoor district in Andhra Pradesh for sustainable land use planning. *Journal of the Indian Society of Soil Science* 56: 23-33.
- Verma JR and Tripathi D. 2007. Characterization and classification of some soils of mid Shivalik hills of Himachal Pradesh. *Annals of Plant and Soil Research* 9: 58-62.
- Verma KS, Shyampura RS and Jain SP. 1990. Characterization of soils under forests of Kashmir valley. *Journal of the Indian Society of Soil Science* 38: 107-115.
- Verma SD, Kaistha BP and Sharma PK. 1976. Soil toposequence studies on a landscape segment of temperate humid climate in Himachal Pradesh-I. Characterization and classification. *Fertilizer Technology* 13: 224-229.
- Verma SD, Tripathi BR and Kanwar BS. 1985. Soils of Himachal Pradesh and their Management. Fertilizer Association of India, New Delhi. 149-163p.
- Verma TS and Tripathi BR. 1982. Relationship of micronutrient elements in soils growing rice. *Journal of the Indian Society of Soil Science* 30: 89-91.
- Vogel AI. 1978. Text book of quantitative inorganic analysis. Richard clay, The Chances press Ltd., Britain.
- Wadia DN. 1966. Geology of India. SLBS and McMillan and Company. London.
- Walia CS and Chamuah GS. 1990. Characterization, classification and suitability for land use planning of foot hill soils. *Journal of the Indian Society of Soil Science* 38: 286-292.
- Walia CS and Rao YS. 1996. Genesis, characteristics and taxonomic classification of some red soils in Bundel Khand region of Uttar Pradesh. *Journal of the Indian Society of Soil Science* 44: 476-481.
- Walkley A and Black IA. 1934. Examination of the method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science* 37: 29-38.
- Weil RR and Magdoff F. 2004. Significance of soil organic matter to soil quality and health. In: Soil organic matter in sustainable agriculture. CRC press Florida, R R Weil and F Magdoff (eds.), 1-43p.
- Wienhold BJ, Andrews SS and Karlen DL. 2005. Soil Quality: Indices and Appraisal. *Journal of Indian Society of Soil Science Proceedings* 67-72p.

- Wu C, Luo Y and Zhang L. 2010. Variability of copper availability in paddy fields in relation to selected soil properties in south-east China. *Geoderma* 156: 200-206.
- Wutscher HK and Hardesty CA. 1981. Seasonal levels of water extractable cations and anions in soil under blight affected and healthy citrus trees. *Communications in Soil Science & Plant Analysis* 14: 719-731.
- Wutscher HK. 1989. Soil pH and extractable elements under blight affected and healthy citrus trees on six Florida soils. *Journal of American Society of Horticulture Science* 114: 611-614.
- Yuda E. 1985. Growth retardation of satsuma mandarin (*Citrus unshiu* Marc.) in acid soils and preventive measures. *Japanese Journal of Agriculture Research* 18: 202-208.
- Zhou XW, Lu B, Li ZY, Chen XN, Cheng CF and Keyong F. 1996. Nutrient characteristics of sweet orange (*Citrus sinensis* cv. 'Jinching') and the technique of fertilization. *Journal of Fruit Science* 13: 162-166.

APPENDIX -I

List of farmers and villages from where the soil and leaf samples were collected

NAHAN BLOCK			PAONTA SAHIB BLOCK		
S.No.	Village	Farmer Name	S.No.	Village	Farmer Name
1.	Badawan	Pratibha Katoch	1.	Shivpur	Raspal Singh
2.	Ambwala	Jagdarshan Singh	2.	Barotiwala	Mahender Singh
3.	Vikram Bagh	Anu Babu	3.	Bangran	Janardhan Singh
4.	Vikram Bagh	Rameswar Saini	4.	Kanshipur	Jagat Ram
5.	Vikram Bagh	Promla Devi	5.	Gulabgarh	Omkar Singh
6.	Vikram Bagh	Narender Singh Katoch -	6.	Jamniwala	Nek Singh
7.	Aagdiwala	Ashok Kumar	7.	Shamsherpur	Mokam Singh
8.	Vikram Bagh	Rajeev Chauhan	8.	Batamandi	Ved prakash Sharma
9.	Ambwala	Randev	9.	Paonta Sahib	Choudhary Sobhar Singh
10.	Ambwala	Dharampal	10.	Sainwala	Raveenu Swaroop
11.	Shambhuwala	Abhishek Tomar	11.	Kolar	Vivek Chauhan
12.	Ambwala	Inder Solanki	12.	Bhupur	Devidayal
13.	Khaddar ka bagh	Prashant Kanwar	13.	Dhutanpur	Subhod
14.	Khaddar ka bagh	Puneet Kanwar	14.	Paonta Sahib	Hardyal Singh
15.	Keli	Bhagwan Singh	15.	Salwala	Tarun
16.	Keli	Anil Singh	16.	Salwala	Karun
17.	Keli	Ram Kiran	17.	Paonta Sahib	Dalel Singh
18.	Ambwala	Swarn Singh	18.	Shivpur	Sardar Bhol Singh
19.	Aagdiwala	Shakuntala Chauhan	19.	Majra	Shahid Khan
20.	Shikrandi	Shravan Singh	20.	Paonta Sahib	Khushal Singh

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Title of Thesis	:	Soil and Plant nutrient contents in mango (<i>Mangifera indica</i> L.) orchards of Sirmour district of Himachal Pradesh
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ABSTRACT

Investigation entitled “Soil and Plant nutrient contents in mango (*Mangifera indica* L.) orchards in Sirmour district of Himachal Pradesh” was undertaken to ascertain the nutritional status of mango orchards, located in Nahan and Paonta Sahib blocks of Sirmour district and to establish the relationships among soil characteristics and nutrient contents of soils and plants. Based on uniformity in respect of age and tree vigour, 40 representative orchards were selected and “Dashehri” variety of mango was selected for study as most of the well established orchards in these blocks were under this variety. Soil (0-15 and 15-30 cm depths) and plant (leaf) samples collected from mango orchards were analyzed for physico-chemical properties (pH, EC, OC), macro-nutrients (N, P, K, Ca, Mg, S) and micro-nutrients (Zn, Cu, Fe and Mn) status. The pH were nearly neutral in reaction. The electrical conductivity values were in safe limits (less than 0.8 dSm⁻¹). The organic carbon contents were medium to high. Nutrient index values showed that the soils were high in available P, K, Ca, Mg, S, Cu, Fe and Mn except Zn which were medium in sub-surface layers. The soil fertility status indicated that 100 and 70 per cent orchard soils were medium in available N and Zn at Nahan block, while 100, 15 and 55 per cent orchard soils were medium in available N, Cu and Zn at Paonta Sahib block whereas 100 per cent soils were high in available P, K, Ca, Mg, S, Cu, Fe and Mn content at Nahan block and at Paonta Sahib block 100 per cent soils were high in available P, K, Ca, Mg, S, Fe and Mn content. The leaf nutrient status showed that 40, 10, 15 and 25,25, 15 per cent samples were low in Ca, S and Zn in both the blocks respectively, whereas 75, 80, 68, 85, 28, 75 and 50 per cent samples were high in N, P, K, Mg, Cu, Fe and Mn. The per cent coefficient of variations found high in soil and plants could be due to variations in parent material and orchard management practices. Organic carbon was positively and significantly correlated with N, P and K. Available N, K, Mg, S and Mn exhibited positive and significant relationship with their respective leaf nutrient contents.

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