STUDIES ON NUTRIENT STATUS OF LITCHI (*Litchi chinensis* Sonn.) ORCHARDS OF KANGRA DISTRICT OF HIMACHAL PRADESH

Thesis

by

VISHAL CHANDEL
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DEPARTMENT OF SOIL SCIENCE AND WATER MANAGEMENT
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NERI (HAMIRPUR) HP-177 001 INDIA

2020

Dr Anil Kumar
Scientist
(Soil Science)

Department of Soil Science and Water Management
College of Horticulture and Forestry, Neri, Hamirpur
Dr Yashwant SinghParmar University of Horticulture and Forestry, (Nauni), Solan (HP) – 173 230 India

CERTIFICATE-I

This is to certify that the thesis titled, **"Studies on nutrient status of Litchi (*Litchi chinensis* Sonn.) orchards of Kangra district of Himachal Pradesh"** submitted in partial fulfilment of the requirements for the award of degree of **MASTER OF SCIENCE (AGRICULTURE) SOIL SCIENCE** in the discipline of **AGRIULTURAL SCIENCE** to the Dr Yashwant Singh Parmar University of Horticulture and Forestry, (Nauni) Solan (HP) – 173 230 is a bonafide research work carried out by **Mr Vishal Chandel** (NF-2017-06-M) son of Sh Sohan Singh 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 this investigation have been fully acknowledged.

Place: Neri, Hamirpur **(Dr Anil Kumar)**
Date: December, 2019 **Major Advisor**

CERTIFICATE-II

This is to certify that the thesis titled, **"Studies on nutrient status of Litchi (*Litchi chinensis* Sonn.) orchards of Kangra district of Himachal Pradesh"** submitted by **Mr Vishal Chandel** (NF-2017-06-M) son of son of Sh Sohan Singh to the Dr Yashwant Singh Parmar University of Horticulture and Forestry, (Nauni) Solan (HP) -173230 India in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE (AGRICULTURE) SOIL SCIENCE** in the discipline of **AGRIULTURAL SCIENCE** has been approved by the Advisory Committee after an oral examination of the student in collaboration with an External Examiner.

Dr Anil Kumar
Scientist (Soil Science)
Major Advisor

External Examiner

Dean's Nominee

Members of Advisory Committee:

Dr Rakesh Sharma
(Scientist)

Dr Raj Saini
(Assistant Professor)

Dr Som Dev Sharma
Prof. (Fruit Science)

Professor and Head
Department of Soil Science and Water Management
College of Horticulture & Forestry
Neri - Hamirpur (HP)

Countersigned

Dean
College of Horticulture & Forestry
Neri - Hamirpur (HP)

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Place: Neri, Hamirpur

Date: December, 2019 ***(Vishal Chandel)***

CONTENTS

Chapter	Title	Pages
1.	INTRODUCTION	1-2
2.	REVIEW OF LITERATURE	3-30
3.	MATERIALS AND METHODS	31-38
4.	RESULTS AND DISCUSSION	39-72
5.	SUMMARY AND CONCLUSION	73-80
	LITERATURE CITED	81-92
	ABSTRACT	93
	BRIEF BIO-DATA	

ABBREVIATIONS USED

%	Per cent
$\mu g\ g^{-1}$	Micro gram per gram
B.D	Bulk density
Ca	Calcium
cl	Clay loam
cmol $(p^{+})\ kg^{-1}$	Centimole proton per kilogram
Cu	Copper
CV	Coefficient of variance
dSm^{-1}	Deci Siemens per meter
DTPA	Diethylene Triamine Penta Acetic Acid
E	East
EC	Electrical Conductivity
et al.	Co-workers
etc.	*et cetera*
Fe	Iron
FYM	Farm yard manure
$g\ kg^{-1}$	Gram per kilogram
H.P	Himachal Pradesh
HCl	Hydrochloric Acid
i.e.	*That is*
K	Potassium
$kg\ ha^{-1}$	Kilogram per hectare
l	Loam
m	meter
Mg	Magnesium
$mg\ kg^{-1}$	Milligram per kilogram
$Mg\ m^{-3}$	Mega gram per meter cube
mm	Mili meter
Mn	Manganese
N	Nitrogen
N	North
NS	Non significant
OC	Organic carbon
P	Phosphorus
pH	*Puissance de Hydrogen*
ppm	Parts per Million
S	Sulphur
scl	Sandy clay loam
SE±	Standard Error
sl	Sandy loam
sq km	Square kilometer
Viz.	*Videlicet*
Zn	Zinc

LIST OF TABLES

Table	Title	Page
3.1	List of sampling sites of litchi orchards of Kangra district of Himachal Pradesh	33-34
3.2	Analytical methods used for soil analysis	35
3.3	Analytical methods used for plant analysis	36
3.4	Critical limits used for interpretation of chemical properties of the soil	36
3.5	Critical limits of nutrients for plant samples.	37
4.1	Bulk density (Mg m^{-3}) of the litchi orchards soils of Kangra district	40
4.2	Soil texture of the litchi orchards soils of Kangra district	42
4.3	Soil pH and electrical conductivity (dS m^{-1}) of the litchi orchards soils of Kangra district	45
4.4	Organic carbon content (g kg^{-1}) of the litchi orchards soils of Kangra district	46
4.5	Available nitrogen and phosphorus content (kg ha^{-1}) of the litchi orchards soils of Kangra district	48
4.6	Available potassium and sulphur content (kg ha^{-1}) of the litchi orchards soils of Kangra district	50
4.7	Exchangeable calcium and magnesium content [cmol (p^+) kg^{-1}] of the litchi orchards soils of Kangra district	52
4.8	DTPA-extractable iron and copper content (mg kg^{-1}) of the litchi orchards soils of Kangra district	54
4.9	DTPA-extractable manganese and zinc content (mg kg^{-1}) of the litchi orchards soils of Kangra district	56
4.10	Nutrient indices of surface soils of the litchi orchards of Kangra district	57
4.11	Nutrient indices of sub-surface soils of the litchi orchards of Kangra district	58
4.12	Leaf N, P and K content (per cent) in litchi orchards of Kangra district of Himachal Pradesh	59
4.13	Leaf S, Ca and Mg content (per cent) in litchi orchards of Kangra district of Himachal Pradesh	61
4.14	Leaf Fe, Cu, Mn and Zn content (ppm) in litchi orchards of Kangra district of Himachal Pradesh	63
4.15	Plant nutrient status of litchi orchards of Kangra district	64
4.16	Relationship among surface soil characteristics	65
4.17	Relationship among sub-surface soil characteristics	67
4.18	Relationship of surface soil characteristics with the leaf nutrient	70

	content	
4.19	Relationship of sub-surface soil characteristics with the leaf nutrient content	71

LIST OF FIGURES

Figure	TITLE	Between Pages
4.1	Percentage distribution of textural classes in surface soils (0 to 15 cm)	43
4.2	Percentage distribution of textural classes in sub-surface soils (15 to 30 cm)	43

Chapter-1

INTRODUCTION

Litchi (*Litchi chinensis* Sonn.) is an important subtropical perennial fruit crop grown in the foothill regions of Himachal Pradesh. It belongs to the family Sapindaceae and is believed to have originated in the Kwantung and Fukien areas of Southern China. It is also known as queen of the fruits due to its attractive deep pink/red colour and fragrant aril. India is the second largest producer of litchi after China. The five largest world's Litchi producing countries are China, India, Taiwan, Thailand and Vietnam. In India, litchi is successfully grown in Assam, Bihar, Orissa, West Bengal, Tripura, Punjab, Uttaranchal, Himachal Pradesh and Maharashtra and occupies an area of 92.1 thousand hectare with an annual production of 583.4 thousand metric tonnes and productivity of 6.5 metric tonnes per hectare (Anonymous, 2017).

In Himachal Pradesh, litchi is grown in some pockets of Kangra, Hamirpur, Una, Bilaspur, Sirmour, Solan, Chamba and Mandi districts. Himachal Pradesh produces 5469 metric tonnes of litchi in an area of 5673 hectare (Anonymous, 2017). Kangra in Himachal Pradesh has earned the distinction of being pioneer district in the cultivation of litchi, producing 3231 metric tonnes of fruit in a year (Anonymous, 2017). The main litchi varieties under cultivation in Himachal Pradesh are Dehradun and Culcuttia.

The population of our country is rising at an exponential pace, which puts greater pressure on soil resources. Nutrition of fruit plants depends upon inherent ability of soil to supply nutrient elements. The key to better management of mineral nutrition to the plants is the judicious use of fertilizers based on laboratory analysis values. Plant analysis is used to confirm the suspected deficiencies and toxicities of nutrients and also helps in assessing the efficiency of fertilizer treatments.

Soil is the resource of essential plant nutrients and thus, its chemical and physical properties are of fundamental importance. Soil fertility refers to the inherent capacity of a soil to supply essential nutrients to plant in adequate amount, in correct proportion and at the right time for their optimum growth. The nutrient status or the fertility status of the soil is the net effect of many interacting factors such as micro-organism activity, organic matter, pH, soil forming factors, management practices etc and is monitored by pedogenic (climate, microorganism, parent material, topography and time) as well as artificial land use and management practices. The mineral interaction in soil can be very complicated as supply of one nutrient can affect uptake or utilization of another nutrient. One element may counter or depress the effect of another (antagonism) or enhance the impact of another (synergism) depending upon various situations.

The physical and chemical characteristics of soil are the main parameters, which affects the productivity of fruit crops. Further, the climatic factors in association with physico-chemical properties help in determining the crop growth. It has been reported that the characteristics of the soil strongly influence the availability of nutrients and ultimately the growth, development and yield of fruit trees (Bhandari and Randhawa, 1985).

Plants are the best indicators of the nutrient availability in the soil in a given set of environmental conditions. The leaves are the nutritional centre of the plants; therefore, they form the basis of leaf analysis. Leaf analysis not only serves as a better guide for fertilizer use and planning but it also helps in understanding the relationship between the soil and the plant.

The new improvised varieties of litchi are highly responsive to the application of various fertilizers and they deplete the nutrients quickly from the soil. Litchi requires various macro and micro nutrients whose availability differs from region to region depending upon the climate, organisms, parent material, topography, time, land use and management practices etc. Therefore, in order to increase the productivity and profits in litchi the fertilizers are to be applied in right quantities to avoid any deficiency and toxicity symptoms. The information generated through soil and plant analysis helps in application of the fertilizers in correct doses without putting any economic burden on the farmers. Thus, the present investigation entiled "**Studies on nutrient status of Litchi (*Litchi chinensis* Sonn.) orchards of Kangra district of Himachal Pradesh**" have been envisaged with the following objectives:

(i) To study the nutritional status of Litchi orchards of Kangra district.

(ii) To study the relationships of soil characteristics with the available soil and leaf nutrient contents.

Chapter-2

REVIEW OF LITERATURE

The analysis of nutrient is performed in order to assess the nutrient that is present in the soil which provides all the necessary information that is required in order to set the target of nutrient application. It also allows the detection and monitoring of the changes in the parameters of the soil. Soil tests and leaf analysis are a valuable tools that helps growers to make better management decisions about fruit nutrition. Hence, the present study entitled "**Studies on nutrient status of Litchi (*Litchi chinensis* Sonn.) orchards of Kangra district of Himachal Pradesh**" is reviewed in this section under the following heads:

2.1 Physico-chemical properties of the soil

- **2.1.1 Physical properties**
- **2.1.2 Chemical properties**

2.2 Nutrient concentration in plant leaves

- **2.2.1 Macronutrient concentration in plant leaves**
- **2.2.2 Micronutrient concentration in plant leaves**

2.3 Relationship of soil characteristics with the available soil and leaf nutrient contents

- **2.3.1 Relationship of soil characteristics with the available soil nutrient contents**
- **2.3.2 Relationship of soil characteristics with the leaf nutrient contents**

2.1 PHYSICO-CHEMICAL PROPERTIES OF THE SOIL

2.1.1. Physical properties

I. Soil bulk density

Soil fertility status of Bari (upland) and Khet (irrigated low land) in small watershed of Mid-hill region of Nepal were assessed by Regmi and Zoebisch (2004). They reported that the bulk density of Khet land was generally higher than Bari land and average values were 1.36 and 1.28 Mg m^{-3}, respectively.

The characterization and classification of rice growing soils of Palam valley was carried out by Kumar and Verma (2005) and observed an increase in bulk density with increasing depth in all pedons and values varied between 0.99 to 1.62 Mg m^{-3}.

Shekhar (2009) found that in the surface soil of forest, grasslands and cultivated areas, the bulk density varied from 1.14 to 1.31, 1.19 to 1.26 and 1.31 to 1.34 Mg m^{-3}, respectively. The respective values in sub-surface soils varied from 1.31 to 1.48, 1.35 to 1.48 and 1.46 to 1.52 Mg m^{-3}. The surface soils of forest, grassland and cultivated areas recorded the average bulk density of 1.2 ± 0.07, 1.2 ± 0.03 and 1.3 ± 0.02 Mg m^{-3}, respectively and in the sub-surface soils the corresponding values were 1.4 ± 0.07, 1.4 ± 0.06 and 1.5 ± 0.02 Mg m^{-3}. According to Akbar *et al*. (2010) the bulk density of rehabilitated forest varied from 0.7 to 1.29 Mg m^{-3} and that of secondary forest from 0.64 to 0.76 Mg m^{-3}.

While, studying the fertility status of alluvial, medium black soils and ravenous land of Chambal region of Madhya Pradesh, Singh *et al*. (2014) reported that the bulk density of alluvial, medium black and ravinous land ranged from 1.49 to 1.45, 1.46 to 1.55 and 1.55 to 1.62 Mg m^{-3} having average value of 1.53, 1.51 and 1.59 Mg m^{-3}, respectively. The highest bulk density was observed in ravenous land followed by alluvial and medium black soil.

Kumar *et al*. (2017) carried out a preliminary survey in cold arid soils of Spiti valley of Himachal Pradesh to measure the status and distribution of available micronutrient in relation to physico-chemical properties under different land uses and found that the bulk density on the surface soils of cultivated land of annual crops, cultivated lands under apple plantation and pasture land varied from 1.20 to 1.37, 1.25 to 1.28 and 1.23 to 1.38 Mg m^{-3}, respectively. However, in sub-surface layer it varied from 1.20 to 1.55, 1.23 to 1.28 and 1.17 to 1.26 Mg m^{-3}, respectively.

Comprehensive database about the fertility status of soils of different villages of Majhawa block of Mirjapur district was prepared by Singh *et al.* (2017). They revealed that the bulk density of surface soil was lower than sub-surface soil ranging between 1.29 to 1.39 Mg m^{-3}, respectively. Whereas, in sub-surface soils bulk density varied from 1.36 to 1.42 and Mg m^{-3}, respectively. The mean bulk densities in surface and sub-surface soil were 1.31 and 1.39 Mg m^{-3}, respectively.

Kumar and Paliyal (2018) observed that in surface soils of vegetable, paddy and maize growing areas, bulk density ranged from 1.0 to 1.28, 1.07 to 1.29 and 1.09 to 1.29 Mg m^{-3}, respectively. However, it varied from and 1.07 to 1.30, 1.09 to 1.32 and 1.1 to 1.34 Mg m^{-3}, respectively in sub-surface layer. The bulk density increased with soil depth in all the mid-hill zone of Himachal Pradesh.

II. Soil texture

Sharma *et al.* (2002) found that the soil textural classes in the Fatehpur block of Kangra district of Himachal Pradesh varied from sandy to silty clay loam.

In Tonk district of Rajasthan the soil texture varied from loamy sand to clayey soil and the clay content varied from 7.71 to 42.40 per cent (Meena *et al.,* 2006).

Sharma and Kanwar (2012) studied the soils of Kinnaur and Lahaul and Spiti and concluded that the clay content in soils varied from 4.0 to 23.2 per cent with an average value of 13.9 per cent.

Chohan *et al.* (2015) determined the soil physico-chemical properties with available plant macronutrients in Taluka Ghora Bari district Thatta, Sindh, Pakistan. They found higher clay content than silt and sand content in surface soil while in subsurface soils the sand particles were higher.

Khadka *et al.* (2016) assessed the soil fertility status of Agriculture Research Station, Belachapi, Dhanusha, Nepal and found that the silt content varied from 8.2 to 67.6 per cent with an average value of 36.03 per cent and clay content varied from 12.8 to 68.8 per cent with an average value of 25.42 per cent.

While, studying the fertility status of Mid-Himalyan region of Solan district of Himachal Pradesh, Annepu *et al.* (2017) found that the soil varied from loamy to sandy loam in texture.

Kumari *et al.* (2017) reported that sand, silt and clay contents in the soils of Himachal Pradesh varied from 19.3 to 74.6, 14.6 to 43.6 and 5.8 to 36.2 per cent, respectively. The textural class varied from sandy loam to sandy clay loam.

Distribution of available macronutrient in relation to physico-chemical properties under different land uses of cold arid soils of Spiti valley of Himachal Pradesh was assessed by Kumar *et al.* (2017) and a little variation in clay and almost no variation in sand and silt content was reported. The textural class of Spiti valley was found to be sandy loam, loam and sandy clay loam.

2.1.2. Chemical properties

I. Soil pH

Several workers (Walia and Chamuah, 1990; Gangopadhyay *et al.*, 1990; Verma *et al.*, 1990; Sahu and Patnaik, 1990) revealed that the soil pH values varied between 4.3 and 9.9 in different regions of the country. In the central Himalayas of Himachal Pradesh, the pH values ranged from 6.7 to 7.7 (Kaistha and Gupta, 1993), while, at the mid altitude of the external Himalayas, the pH varied from 6.5 to 8.4 (Singh *et al.*, 1991) and in the soils of the north-western Himalayas the pH value ranged from 5.1 to 9.8 (Kaistha *et al.*, 1990).

A study was carried out by Tripathi *et al.* (1992) in some apple orchards soils of Mandi district and reported that the soils were acidic to slightly alkaline (pH 5.2 to 7.8).

Minhas *et al.* (1997) studied the morphological characteristic of the soil profiles in the Wet Temperate Zone of Himachal Pradesh and reported that the soil pH ranged from 5.3 to 6.5 in the cultivated soils of Palampur and Ahju and the soils were moderately to strongly acidic. While, at the relatively lower altitudes (about 1200 m), the pH of the Darang, Palampur and Ahju soils were less acidic.

Rice growing soils of upper Brahmputra Valley of Assam was studied by Gangopadhyay *et al*. (1998). They found that the surface soils were moderately acidic (pH 4.7 to 5.7) and in the sub-surface, the soil pH was slightly acidic to nearly neutral (pH 5.0 to 6.8).

Physico-chemical characteristic of the Outer Himalayas soil was studied by Chaudhary *et al.* (2005) and they observed that the pH of the outer Himalayan soils varied from slightly acidic (pH 6.0) to mildly alkaline (8.3) and increased with depth.

The pH of the Kashmir soils varied from 6.7 to 7.2 which mean that the soils were almost neutral in nature (Najar *et al.*, 2009).

Sharma and Kanwar (2010) studied the physico-chemical properties of soil at different location of dry temperate zone of Himachal Pradesh and observed that the soil pH ranged from 6.2 to 10.3 with a mean value of 7.6.

Medhe *et al*. (2012) found that the soils of Chakur tehsil were neutral to alkaline in reaction having an average pH value of 7.56.

Soil fertility status of available major and micronutrients in Vertisol of Kabeedham district of Chhattisgarh was evaluated by Kumar *et al.* (2014) and found that the soil pH varied from 6.9 to 8.5 with an average value of 7.7.

The soil reaction in the Thrisur district of Kerala varied from strongly acidic to slightly alkaline as reported by Kavitha and Sujatha (2015).

The soil pH in the mid hill zone of Himachal Pradesh were predominantly neutral to slightly acidic in reaction (Annepu *et al.*, 2017).

II. Electrical Conductivity (EC)

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

Singh *et al.* (2005) found that the electrical conductivity ranged from 0.16 to 0.35 dS m^{-1} in the surface and from 0.09 to 0.22 dS m^{-1} in the sub-surface soils of Uttaranchal and decreased with increasing depth.

In the submontane regions of Punjab, Hundal *et al.* (2005) found that the electrical conductivity of mango fruit orchards ranged from 0.08 to 0.58 dS m^{-1}.

Tripathi *et al.* (2005) analyzed the soils of five agroclimatic areas covering the district of Himachal Pradesh, Kangra, Kinnaur, Sirmour, Chamba and Bilaspur. The average electrical conductivity of the soils of different districts were: Bilaspur 0.24 dS m^{-1}, Chamba 0.26 dS m^{-1}, Kangra 0.15 dS m^{-1}, Kinnaur 0.37 dS m^{-1} and Sirmour 0.20 dS m^{-1} and the mean of all the soils were 0.24 dS m^{-1}.

Verma and Tripathi (2007) reported that the soils of the central hills of Shiwalik in Himachal Pradesh had a very low soluble salt concentration with electrical conductivity values between 0.01 and 0.15 dS m^{-1}.

A study carried out by Perveen *et al.* (2010) in the vegetable growing soils of Peshawar and they showed that electrical conductivity in surface soil varied from 0.13 to 0.56 dSm^{-1}, while in the sub-surface soil it varied from 0.11 to 0.45 dSm^{-1}.

While evaluating the soil fertility status of soil from Sangamner area and Ahmednagar district of Maharashtra, India, Deshmukh (2012) found that the EC varied from 0.1 to 46.8 dSm^{-1}.

Doneriya *et al*. (2013) assessed the soil fertility status of Marihan block of Vindhyan region of Mirzapur district. They showed that the total soluble salt content expressed as electrical conductivity ranged from 0.022 to 0.093 dSm^{-1} with an average value of 0.065 dSm^{-1}.

Soil fertility status of available major and micronutrients in Vertisol of Kabeedham district of Chhattisgarh was evaluated by Kumar *et al*. (2014). They found that the electrical conductivity varied from 0.01 to 0.57 dSm^{-1} with an average value of 0.22 dSm^{-1}.

Kavitha and Sujatha (2015) evaluated the soil fertility status in the eight major agro-eco system in the Thrisur district of Kerala and observed that the electrical conductivity of soils of various agro-eco system of the study area varied from 0.01-0.58 dSm^{-1}.

The EC of soil in the mid hill zone of Himachal Pradesh varied from 0.049 to 0.793 dSm^{-1} with a mean value of 0.426 dSm^{-1} as reported by Annepu *et al*. (2017).

An investigations were carried out by Mogta and Sharma (2018) in four district of Himachal Pradesh i.e. Shimla, Solan, Sirmour and Bilaspur to assess the impact of intensive cropping on availability of soil nutrients and they reported that the soils are low in soluble salt concentration with mean EC values ranged from 0.83 to 1.33 dSm^{-1} and 0.42 to 0.59 dSm^{-1} in the surface and subsurface soil respectively.

Krishna *et al*. (2018) assessed the fertility status of Palari block, Baloda Bazar district, Chhattisgarh. They found that the electrical conductivity ranged from 0.08 to 0.63 $dSm^{-1,}$ with an average value of 0.2 dSm^{-1}.

III. Organic Carbon

Bishnoi *et al.* (1983) found that the organic carbon content in different locations of Himachal Pradesh ranged between 0.19 and 5.43 per cent.

Studies conducted 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 increasing elevation. It was also observed that the organic carbon content was high in surface horizons, which decreased sharply in the sub-soil horizons of the profiles.

It has been reported that the organic carbon content varied from 0.3 to 8.3 per cent in soils of different regions of Himachal Pradesh (Kaistha *et al.* 1990). A moderately high amount of organic carbon (1.40 to 2.58 per cent) was recorded in medium-altitude soils in the outer Himalayas. The organic carbon content in the surface horizons of forest soils has increased with increasing altitude (from 0.9 to 3.6 per cent). Singh *et al.* (1991) and Tripathi *et al.* (1992) stated that the organic carbon content in the soils of the Mandi district varied between 0.20 and 2.6 per cent.

Kaistha and Gupta (1993) and Minhas *et al.* (1997) informed that if the soil depth increased, the organic carbon content rapidly decreased. The increase in the organic carbon content with increasing altitude was due to the continued addition of waste and the slow decomposition of organic waste at low temperatures. The cultivated lands of Palampur and Ahju in the Kangra district of Himachal Pradesh contained lesser amounts of organic carbon.

Sarkar and Sahoo (2000) found that the organic carbon content in the soil ranged from 0.08 to 0.86 per cent, which gradually decreased with the depth of the Indo-Gangetic plains of Bihar. A study was conducted by Nazif *et al*. (2006) at district Bhmber, Azad Jammu and Kashmir and they reported that the organic carbon content varied from 0.65 to 2.07 per cent with an average value of 1.18 per cent. However, Verma and Tripathi (2007) had studied the soil status of the Shivalik hills in Himachal Pradesh and reported that these soils, in general, contain a large invariable amount of organic carbon ranging from 0.10 to 2.77 per cent.

Soil organic carbon content under forest, grassland and cultivated lands varied from 11.2 to 24.0. 10.5 to 18.4 and 7.6 to 11.0 g kg^{-1} in the surface soils whereas in sub-surface, it varied from 3.7 to 7.3, 5.9 to 10.0 and 2.6 to 7.7 g kg^{-1}, respectively (Shekhar, 2009).

Najar *et al.* (2009) found that the organic carbon content in north-facing pedons varied from 0.16 to 3.5 per cent, while in the southern aspect it varied from 0.1 to 2.4 per cent in the apple growing soils of the Kashmir valley.

In the soils of dry temperate zone of Himachal Pradesh, the organic carbon content varied from 0.42 to 4.08 per cent (Sharma and Kanwar, 2010).

A research by Kumar *et al.* (2012) on mango orchards in Uttar-Pradesh found that the most of the soil samples were low in organic carbon content.

Abraham *et al*. (2014) examined the soil fertility status of three rice farms in Yola Metropolis and Adamawa state, Nigeria. Their results revealed that the soil organic carbon content ranged from 1.45 to 4.65 per cent and it decreased with soil depth.

Naik *et al.* (2015) studied the soil fertility status of several mango orchards and reported that the organic carbon content in surface soil layer varied from 6.2 to 6.3 g kg^{-1}.

The soil fertility status of Hassan district of Karnataka, India was evaluated by Basavaraja *et al*. (2017) and showed that the organic carbon content fell low in 37.07 per cent samples, 28.42 per cent were medium, and 34.50 per cent were high in organic carbon.

Krishna *et al*. (2018) studied the fertility status of Palari block, Baloda Bazar district, Chhattisgarh and they found that the status of organic carbon in soils of Palari block was low to medium and varied from 0.22 to 0.80 per cent with an average value of 0.48 per cent.

Mogta and Sharma (2018) studied the nutrient status of four districts of Himachal Pradesh i.e. Shimla, Solan, Sirmaur and Bilaspur and found that the polyhouse surface soils of these study area were rich in organic carbon content and varied from 11.59 to 19.51 g kg^{-1}.

IV. Available Nitrogen

Mahajan (2001) noted that the available nitrogen content was medium (384 to 492 kg ha^{-1}) in the lands of Mandi district of Himachal Pradesh. Motsara (2002) reported that out of 36,50,004 Indian soil samples, the percentage of soil samples that fell into the low, medium and high categories were 63, 26 and 11, respectively in case of nitrogen.

Sharma *et al.* (2002) reported that the available nitrogen content in the soils of the Fatehpur block of Himachal Pradesh were low to high. While, Kumar and Verma (2005) reported that available nitrogen in that soils were low to medium in Palam valley in Himachal Pradesh.

Laxminarayan (2006) reported that the available nitrogen content in the Mizoram soils varied from 213 to 452 kg ha^{-1}. Sharma *et al.* (2008) reported that the available N ranged from 63 to 170 kg ha^{-1} in the soils of Amritsar district.

The cultivated lands of the sweet orange in the Jalna district of Maharashtra, Dhale and Prasad (2009) reported that the available nitrogen content ranged from 68 to 330 kg ha^{-1}. In Andhra Pradesh lands, the available nitrogen content varied from 133 to 188 kg ha^{-1} and the content decreased with depth (Rajeshwar *et al.*, 2009).

Kumar and Prasad (2010) defined the Maharashtra soils that grow with sugarcane and found that the soils are medium in available nitrogen. Sahoo *et al.* (2010) assessed the available nitrogen content in the agricultural lands of Manipur and reported that in these soils it varied from medium to high (503 to 1078 kg ha^{-1}).

Sharma and Kanwar (2012) reported that the soils of the Gondhla valley were deficient in maximum available nitrogen (73 per cent), followed by Kinnaur (48 per cent), Spiti (46 per cent), Pattan Valley (43 per cent) and the Udaipur valley (28 per cent).

Chander *et al*. (2014) found that available nitrogen were medium in soils and ranged from 282 to 439 kg ha^{-1} in majority of soils in mid-hills sub-humid and high-hills wet-temperate sub-agro climatic zones of Himachal Pradesh.

Singh *et al.* (2014) revealed that the range of available N was 126 to 361 kg ha^{-1} in alluvial soil; 178 to 408, kg ha^{-1} in medium black soil and 125 to 301 kg ha^{-1} in ravinous land. Of alluvial soil samples, 97% were low and 3% medium in N. Of medium black soil samples, 90% were low and 10% medium in N. Of ravinous land soil samples, 95% were low and 5% medium in N.

Khadka *et al*. (2016) studied the soil fertility status of the Agriculture Research Station, Belachapi, Dhanusha, Nepal and they found that the total nitrogen content ranged from 0.04 to 0.09 per cent with a mean value of 0.08 per cent. In overall, available nitrogen status was medium.

Kumar *et al*. (2017) collected soil samples randomly from cultivated (annual crops, apple plantation) and pasture lands of cold arid Spiti valley in Himachal Pradesh and they found that the available nitrogen content of surface soils varied from 109 to 407, 188 to 256 and 125 to 250 kg ha^{-1}, respectively. In overall, the available nitrogen status in Spiti valley soil was found low.

Chavada *et al*. (2018) revealed that the available nitrogen ranged from 78.6 to 376.3 kg ha^{-1} with a mean value of 231.8 kg ha^{-1} in soils of Ghandhi nagar district of Gujarat. Out of 160 soil samples, 79.38 per cent were found to be low in available nitrogen status.

Krishna *et al*. (2018) evaluated the fertility status of Palari block, Baloda bazar district, Chhattisgarh and they found that the available nitrogen content ranged from 102 to 277 kg ha^{-1} with a mean value of 157 kg ha^{-1}.

IV. Available phosphorus

The available phosphorus in the cultivated soils of Kangra region of Himachal Pradesh was low as reported by Verma *et al*. (1976). Ghosh and Hasan (1979) stated that the available phosphorus in Indian soils was low, medium and high to the extent of 2, 46 and 52, per cent, respectively. The available P content ranged from 2.69 to 28.22 kg ha^{-1} when characterization of the soils of Kangra, Kullu, Mandi and Sirmour district was done by Verma *et al.* (1985).

The available phosphorus in the citrus growing soils of Ponta valley of Himachal Pradesh was reported to be medium to high (Raina, 1988). With increase in soil depth a decrease in available phosphorus was found by various workers (Sood *et al.,* 1991; Dongale, 1993). In tea growing soils of Assam, available phosphorus content varied from 13.44 to 20.16 kg ha^{-1} (Patgiri and Datta, 1993).

In the soil surface, available phosphorus content was high and decreased downward with increasing depth (Khan *et al.,* 1997). The available phosphorus status in the soils of Loon watershed of Kangra district was medium as found by Sharma *et al*. (1998). In different soil association of district Kanpur in Uttar Pradesh there was a wide variability in the availability of phosphorus (Pandey *et al.,* 2000).

The available phosphorus was reported to be medium which varied from 17 to 22 kg ha^{-1} in the soils of Mandi district of Himachal Pardesh (Mahajan, 2001).

Motsara (2002) observed that out of 36,50,004 samples of Indian soil, 20, 38 and 42 per cent soil samples were low, medium and high for the availability of phosphorus, respectively.

Sharma *et al.* (2002) reported that the lands of the Fatehpur block in Himachal Pradesh were low or high in the available phosphorus content, while Sharma and Kumar (2003) reported that the agricultural lands of the Himachal Pradesh were low to medium in available phosphorus content.

Hundal *et al.* (2005) carried out a study on DRIS to recognize the nutritional status of mango orchards soils in Punjab and revealed that available phosphorus content was low in these soils.

Kumar and Verma (2005) studied the fertility status of rice growing fields in the Palam Valley of Himachal Pradesh and found that the soils of rice growing fields were low to medium in available phosphorus content.

Tripathi *et al.* (2007) studied the status of nitrogen, phosphorus and potassium in the soils of the hills of the northwestern Himalayas and found that the average phosphorus content was 28 kg ha^{-1}.

Sharma *et al.* (2008) reported that the available P ranged from 9.4 to 84.9 kg ha^{-1} in the soils of Amritsar district. Bali *et al.* (2010) characterized the soils of Punjab- North- West India and they found that the available phosphorus content ranged from 1.12 to 238 kg ha^{-1} with an average value of 42.77 kg ha^{-1}. They also observed that only 17.83 per cent area of the state was medium in available phosphorus.

Mustafa *et al*. (2011) characterized the soils of Kheragarah, Agra and they found that the soils were low to high in available P. The available P in the surface layer varied from 7.00 to 70.67 kg ha^{-1} whereas in the sub-surface layers it ranged from 2.31 to 19.29 kg ha^{-1} with an average values of 35.62 and 8.45 kg ha^{-1}, respectively.

Jatav *et al*. (2013) examined the spatial distribution of available nutrient in the soils of Hoshiarpur district of Punjab and found that 11.3 per cent of soil samples were medium in available P content and 88.7 per cent soil samples were high in available P content.

Chander *et al*. (2014) found that available phosphorus was low to medium in soils and ranged from 2.3 to 37.0 kg ha^{-1} in majority of soils in mid-hills sub-humid and high-hills wet-temperate sub-agro climatic zones of Himachal Pradesh. The soils of high-hill-wet temperate zone contained lesser content of available phosphorus.

Hailu *et al*. (2015) studied the fertility status of central highlands of Ethiopia and reported that the available P content in the study area ranged from 3.8 and 14.6 mg kg^{-1}.

Kumar *et al*. (2017) collected soil samples randomly from cultivated (annual crops, apple plantation) and pasture lands of cold arid Spiti valley in Himachal Pradesh and found that the available phosphorus content ranged from 4 to 82, 20 to 53 and 13 to 80 kg ha^{-1} under cultivated lands (annual crops), cultivated lands (apple plantation) and pasture lands, respectively.

Chavada *et al*. (2018) revealed that the available phosphorus content ranged from 18.61 to 69.57 kg ha^{-1} with a mean value of 41.06 kg ha^{-1} in soils of Ghandhi nagar district of Gujarat and 71.88 per cent of soils were medium in available phosphorus status.

Krishna *et al*. (2018) studied the fertility status of Palari block, Baloda bazar district, Chhattisgarh. Their study revealed that the available phosphorus ranged from 1.34 to 26.61 kg ha^{-1} with a mean value of 13.8 kg ha^{-1}.

VI. Available potassium

The soils of India were medium in available K as stated by (Ramamoorthy and Bajaj, 1969). During the study of Indian soils, it was found that 42, 38 and 20 per cent soils to be medium, high and low, respectively in available potassium (Ghosh and Hasan, 1976).

Available K was low in cultivated soils of Kangra district of Himachal Pradesh (Verma *et al.,* 1976). During characterization the soils of Kangra, Kullu, Mandi and Sirmour areas of Himachal Pradesh ranged from 40.26 to 1507 kg ha^{-1} (Verma *et al.,* 1985). Medium levels of potassium in citrus growing soils of Ponta valley of Himachal Pradesh was reported by (Raina, 1988). The soils of Loon watershed of Kangra district of Himachal Pradesh are medium in available K (Sharma *et al.,* 1998).

In the soils of Konkan coast (Maharashtra) the available K content varied from 130 to 350 kg ha^{-1} in surface soils (Powar and Mehta, 1999). On Majalgoan Canal Command area of Maharashtra the available K content varied from 508 to 1321 kg ha^{-1}, indicating high K content (Bharambe *et al.,* 1999).

The soils of Fatehpur block in Himachal Pradesh were low to medium in available K (Sharma *et al.,*2002). The soils of agriculture lands of mid hill zone of Himachal Pradesh were low to high in available K as reported by Sharma and Kumar (2003).

During the study of fertility status of rice growing soils of Palam valley of Himachal Pradesh it was reported that the soils were low to high in available K (Kumar and Verma, 2005). The status of potassium in the hill soils of North-Western Himalayas was studied by Tripathi *et al*. (2007) and found an average K content of 289 kg ha^{-1}.

The available K was medium to high during the characterization of the grassland's soils of Andhra Pradesh (Vara Prasad Rao *et al*., 2008).

While characterizing and classifying the sweet orange growing soils of Jalna district of Maharashtra, Dhale and Prasad (2009) found that available K content ranged from 195 to 1287 kg ha^{-1}. Rajeswhar *et al*. (2009) reported that the available K content varied from 110 to 389 kg ha^{-1} which decreased with increasing depth.

Potassium content was found to be medium to high during the characterization of the sugarcane growing soils of Maharashtra (Kumar and Prasad, 2010). However, Sahoo *et al.* (2010) rated the soils of the agricultural lands of Manipur as low to high in available K (79 to 440 kg ha^{-1}).

Nearly 83 per cent of soil samples were reported to be high in available K and the availability of K showed a decreasing trend with soil depth. (Sharma and Kanwar, 2012). The K content of the polyhouse soils of Mandi, Solan and Sirmour district ranged from 224 to 1039.4, 227.40 to 776.2 and 229.60 to 902.72 kg ha^{-1}, respectively (Chandel, 2013).

Chander *et al*. (2014) found that majority of soils in mid-hills sub- humid and high-hills wet-temperate sub-agro climatic zones of Himachal Pradesh were medium to high in available potassium. The soils of high-hill-wet temperate zone contained lesser content of available potassium in comparison to soils in sub humid zones.

Hailu *et al*. (2015) studied the fertility status of central highlands of Ethiopia and reported that the available K in the study area ranged from 1.2 to 2.1 mg kg^{-1}. Mustafa *et al*. (2016) studied the six pedons of the Kheragarah tehsil of Agra district and found medium to high available K ranging from 153.0 to 361.6 kg ha^{-1}.

Kumar *et al*. (2017) collected soil samples randomly from cultivated (annual crops, apple plantation) and pasture lands of cold arid Spiti valley in Himachal Pradesh and found that available potassium in surface horizons was 22 to 260, 41 to 108 and 94 to 238 kg ha^{-1}

under cultivated lands (annual crops), cultivated lands (apple plantation) and pasture lands, respectively.

Chavada *et al*. (2018) revealed that the potassium content ranged from 114.24 to 645.33 kg ha^{-1} with a mean value of 306 kg ha^{-1} in soils of Ghandhi nagar district of Gujarat and they further reported that 50 per cent soil samples were high in available potassium status.

Krishna *et al*. (2018) studied the fertility status of Palari block, Baloda bazar district, Chhattisgarh and their study revealed that the available K content ranged from 113 to 567 kg ha^{-1} with an average value of 238 kg ha^{-1}.

VII. Calcium

The soils of North-West Himalayas exchangeable Ca was found to vary from 2.2 to 10.5 [cmol (p^+) kg^{-1}] (Gupta and Tripathi, 1989) and 3.7 to 15.3 [cmol (p^+) kg^{-1}] in the soils of Central Himalayas of Himachal Pradesh representing sub-humid temperate high lands (Kaistha and Gupta, 1993). In wet Temperate soils of Himachal Pradesh, the exchangeable Ca varied from 2.1 to 20.0 [cmol (p^+) kg^{-1}] (Minhas *et al*., 1997).

The majority of soils of Himachal Pradesh were deficient in Ca (Sharma *et al.*, 2001). The soils of Mandi district in Himachal Pradesh were reported high in exchangeable Ca ranged from 4.0 to 5.1 [cmol (p^+) kg^{-1}] (Mahajan, 2001).

Sharma *et al*. (2002) collected seven hundred composite soil samples from Fathepur block of Kangra district of Himachal Pradesh and reported that the exchangeable Ca content varied from 56 to 1303 kg ha^{-1}. The soils were sufficient in exchangeable Ca.

On characterizing and classifying sweet orange growing soils of Jalna district of Maharashtra, Dhale and Prasad (2009) reported that the exchangeable Ca content varied from 24.48 to 55.61 [cmol (p^+) kg^{-1}].

While characterizing the soils of Siwalik Hills and undulating eco-sub region of Punjab, Bali *et al.* (2010) observed that the exchangeable Ca ranged from 2.8 to 10.4 [cmol (p^+) kg^{-1}], with a mean value of [6.08 cmol (p^+) kg^{-1}].

Medhe *et al.* (2012) collected hundred surface soil samples to study the chemical properties and available nutrient status of soils from Chakur tehsil of Latur district, Maharastra and revealed that the exchangeable Ca content in soil was ranged from 18.4 to 54.4 [cmol (p^+) kg^{-1}] with the mean value of 33.51 [cmol (p^+) kg^{-1}].

A study was conducted by Kavitha and Sujatha (2015) in the eight major agro ecosystems at Thrissur district of Kerala. They concluded that in various agro-ecosystems the Ca content in soils varied from 20.6 to 3515 ppm.

The study carried out by Khadka *et al.* (2016) at Agricultural Research Station, Belachapi, Dhanusha, Nepal and they found that the exchangeable Ca content was ranged from 180 to 2080 ppm with an average value of 1264.80 ppm.

Kumar *et al.* (2017) studied the cultivated (annual crops and apple plantation) and pasture lands of cold arid soils of Spiti valley in Himachal Pradesh. They found that exchangeable Ca content of soils ranged between 7.5 to 15.8 and 9.5 to 15.45 [cmol (p^+) kg^{-1}].The soils of Spiti valley were found to be high in exchangeable Ca.

Sharma *et al.* (2018) studied the soils of Kangra district of Himachal Pradesh and found that exchangeable Ca content in surface soils ranged from 3.07 to 5.91 [cmol (p^+) kg^{-1}], whereas their respective content in the sub-surface layers ranged from 3.01 to 5.62 [cmol (p^+) kg^{-1}], respectively.

VIII. Magnesium

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

Majority of soils of Himachal Pradesh was deficient in exchangeable Mg (Sharma *et al.,* 2001). Soils of Fatehpur block in Himachal Pradesh were sufficient in exchangeable Mg (Sharma *et al.,* 2002).

In surface soils of Forest, grasslands and cultivated lands of high rainfall areas in Kangra, Chamba and Mandi districts of Himachal Pradesh, the exchangeable Mg 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}] observed by Shekhar (2009).

Medhe *et al.* (2012) collected hundred surface soil samples to study the chemical properties and available nutrient status of soils from Chakur tehsil of Latur district, Maharastra and revealed that the exchangeable Mg content in soil was ranged from 8.7 to 29.7 [cmol (p^+) kg^{-1}] with a mean value of 16.63 [cmol (p^+) kg^{-1}].

A study was conducted by Kavitha and Sujatha (2015) in the eight major agro ecosystems at Thrissur district of Kerala. They concluded that in various agro ecosystems the Mg content in soils varied from 3.0 to 524.0 ppm.

The study carried out by Khadka *et al.* (2016) at Agricultural Research Station, Belachapi, Dhanusha, Nepal and they found that the extractable Mg content was ranged from 12 to 432 ppm with a mean value of 223.20 ppm.

Kumar *et al*. (2017) studied the cultivated and pasture lands of cold arid soils of Spiti valley in Himachal Pradesh. They found that exchangeable Mg content of soils ranged between 1.16 to 3.77 and 1.24 to 2.95 [cmol (p^+) kg^{-1}], respectively.

Sharma *et al.* (2018) studied the soils of Kangra district of Himachal Pradesh and found that exchangeable Mg content in surface soils ranged from 2.02 to 3.30 [cmol (p^+) kg^{-1}], whereas their respective content in the sub-surface layers ranged from 1.34 to 2.90 [cmol (p^+) kg^{-1}], respectively.

IX. Sulphur

In apple orchards of Mandi district, the sulphate sulphur in surface and sub-surface soil ranged between 7.2 to 29.4 and 6.2 to 30.7 ppm with mean values of 14.3 and 14.9 ppm, respectively (Sharma, 1990). It was found that available sulphate sulphur was low in 15 per cent of surface and 13 per cent of sub-surface samples and others were medium in its availability.

In the soils of Himachal Pradesh, soluble sulphate sulphur content ranged from 5.5 to 21.2 mg kg^{-1} and decreased with increasing depth (Tripathi and Singh, 1992). Majority of the soils of Himachal Pradesh were deficient in sulphate sulphur reported by (Sharma *et al.*, 2001).

Wide variability was reported in the availability of sulphur in different soil association in district Kanpur of Uttar Pradesh and available S content varied from 5.8 to 53.8 mg kg^{-1}

(Pandey *et al.,* 2000). Tandon (2004) indicated that about 37 per cent of Indian soils were low in available sulphur.

Spatial distribution of nitrogen (N), phosphorus (P), potassium (K) and sulphur (S) was studied by Sharma *et al.* (2008) and reported that the available sulphur ranged from 24.6 to 60.0 kg ha^{-1}, in the soils of Amritsar district. They further found that the soils of the district are adequate in S. However, 47, 45 and 8 per cent of the samples were found to be medium, high and very high in available sulphur.

Singh *et al.* (2009) collected five hundred surface soil samples from Udham Singh Nagar district, Uttarakhand. They found that available sulphur varied from 4.6 to 118.4 mg kg^{-1} and 22, 31 and 47 per cent of the soil samples were low, medium and high in available sulphur, respectively.

Chouhan *et al*. (2012) studied the soils of Dewas district of Madhya Pradesh, India, and observed that the available S content ranged from 0.9-50.2 mg kg^{-1}, and reported that about 38.6 per cent of the samples were deficient in available sulphur.

Singh *et al.* (2014) revealed that the available sulphur varied from 6.8 to 33.5 kg ha^{-1} in alluvial soil, 8.5 to 34.4 kg ha^{-1} in medium black soil and 11.5 to 38.8 kg ha^{-1} in ravinous land. Of alluvial soil samples, 41 per cent were medium in available sulphur. Of medium black soil samples, 49 per cent and of ravinous land soil samples, 66 per cent were medium in available sulphur.

Khadka *et al*. (2016) studied the soil fertility status of the Agriculture Research Station, Belachapi, Dhanusha, Nepal. They found that the available sulphur varied from 0.29 to 1.81 ppm with a mean value of 0.73 ppm. In overall, available sulphur was very low in status.

Kumar *et al*. (2017) randomly collected soil samples from cultivated annual crops, cultivated apple plantation and pasture lands of cold arid Spiti valley of Himachal Pradesh and found that the available sulphur varied from 8.4 to 58.8, 16.8 to 42.0 and 29 to 58.8 kg ha^{-1} in surface soils. In overall, the Spiti soils were found high in available sulphur.

Chavada *et al*. (2018) revealed that the available sulphur content ranged from 6.74 to 30.06 mg kg^{-1} with a mean value of 18.97 mg kg^{-1} in the soils of Ghandhi nagar district of Gujarat. Out of 160 soil samples, 48.75 per cent were high in available sulphur status.

X. DTPA-extractable iron

Distribution of micro-nutrients in the soils of Himachal Pradesh was done by Tripathi *et al*. (1994). They stated that Fe content varied from 15 to 41.2 mg kg^{-1} in the soils of Solan district of Himachal Pradesh.

About 12 per cent soils of India were deficient in available Fe (Singh 2001). In the soils of some mulberry garden of Karnatka, the amount of Fe varied from 3.3 to 205.0 mg kg^{-1} and the content decreased with soil depth (Samanta *et al.*, 2002).

In the soils of lower Shivaliks of Solan district the available Fe content ranged from 8.2 to 50.2 mg kg^{-1} and further declined with increasing depth (Sharma and Choudhary, 2007). The content of iron in the Indian soils varied from 3.4 to 68.1 mg kg^{-1} (Rattan *et al.*, 2008).

In the soils of Kheragarh tehsil of Agra, Uttar Pradesh, India, the available iron content ranged from 5.04 to 31.31 ppm with an average value of 11.76 ppm, (Mustafa *et al.*, 2011).

The soils were sufficient in available Fe content and it varied from 8.5 to 195.2 ppm and the mean value was 25.8 ppm in the mango orchards of Malihabad region of Uttar Pradesh (Kumar *et al.*, 2012). The major and micronutrient status of different mango orchards were studied by (Naik *et al.*, 2015) and reported that DTPA extractable Fe content was high in all the soil samples.

A systematic survey was carried out by Doneriya *et al.* (2013) at Marihan block of Mirzapur district. They concluded that available iron, content ranged from 12.21 to 90.49, mg kg^{-1} with an average value of 48.75 mg kg^{-1}.

Verma *et al*. (2013) evaluated the soil fertility status in *Inceptisol* of Malkarauda block in Janjgir district of Chhattisgarh and revealed that the DTPA- extractable Fe varied from 32 to 60.1 mg kg^{-1} with an average value of 21.0 mg kg^{-1}.

Chander *et al*. (2014) studied the micronutrient cation status in vegetable growing soils of sub-humid and wet-temperate zone of Himachal Pradesh and reported that in sub-humid zone, the DTPA- extractable Fe ranged between 10.6 to 70.8 mg kg^{-1} while in wet-temperate zone it ranged between 22.8 to 96.6 mg kg^{-1}.

While evaluating the soil fertility status in various agro-ecosystems of Kerala, Kavitha and Sujatha (2015) revealed that the DTPA-extractable Fe content varied from 0.1 to 675.4 ppm and there was no significant variation between the cropping systems.

Pawar *et al*. (2016) reported that available iron in surface soils varied from 40.36 to 48.41 mg kg^{-1} with an average value of 44.86 mg kg^{-1}.

A study was conducted by Annepu *et al.* (2017) to assess the soil fertility status of mid Himalayan region and observed that the available Fe content ranged between 2.14 to 15.69 ppm with a mean of 7.29 ppm.

Kakar *et al*. (2018) studied the micronutrient status of Saproon valley of Himachal Pradesh and revealed that the DTPA extractable Fe content of the soil ranged from 7.03 to 24.16 mg kg^{-1}.

Rai and Singh (2018) concluded that the available iron content of the soil under five different cropping systems (Maize-oats, Rice-mustard, Moong-Berseem, Agri-horti system and vegetable) varied from 9.45 to 23.54 mg kg^{-1} with a mean value of 18.41, 15.34, 16.34, 21.35 and 16.54 mg kg^{-1}, respectively. Available iron was sufficient in the soils.

XI. DTPA-extractable manganese

Tripathi *et al.* (1994) reported that some soils of Himachal Pradesh were average in available Mn content (29.0 mg kg^{-1}). DTPA extractable Mn was high in the soil of Mandi district of Himachal Pradesh (Mahajan, 2001). Singh (2001) concluded that 5 per cent of Indian soils were deficient in available Mn.

Nazif *et al.* (2006) studied the micronutrient status of soils of district Bhimber (Jammu and Kashmir) and found that the AB-DTPA extractable manganese ranged from 4.59 to 21.08 mg kg^{-1} and was found high in all sites.

In the profiles of lower Shivalik hills of Solan district, the available Mn content ranged from 2.7 to 56.4 mg kg^{-1} and the content decreased with increasing soil depth (Sharma and Choudhary, 2007). The content of DTPA-Mn in the soils of Muktsar district of Punjab varied from 1.16 to 14.38 mg kg^{-1} (Sood *et al.*, 2009). Available Mn in 12 per cent soils of India was reported deficient (Singh, 2009).

An investigation was carried out by Mustafa *et al.* (2011) to characterize and classify the soils of Kheragarh tehsil of Agra, Uttar Pradesh, India and reported that available manganese content ranged from 3.94 to 27.06 ppm with an average value of 11.65 ppm. It was high in the surface horizons and gradually decreased with depth.

Total Mn and DTPA-Mn varied from 27 to 216 mg kg^{-1} and 1.3 to 22.3 mg kg^{-1} having an average value of 104 and 6.5 mg kg^{-1}, respectively (Sharma and Kanwar, 2011). The polyhouse soils of Mandi, Solan and Sirmour districts had DTPA-Mn ranging from 1.14 to 17.84, 2.13 to 6.38 and 0.31 to 35.56 mg kg^{-1}, respectively (Chandel, 2013).

Singh *et al.* (2014) found that 14.3 per cent alluvial soils and 8.8 per cent in medium black soils were deficient in Mn.

Patel *et al.* (2015) studied the soils of most urbanized Raipur area, Chhattisgarh, India and reported that DTPA-extractable Mn in the soils ranged from 205 to 2800 ppm with a mean value of 1178 ± 119 ppm.

Basavaraja *et al.* **(**2017) evaluated soil fertility status in Hassan district of Karnataka and they found that the DTPA- extractable Mn were sufficient in all the soil samples.

Kakar *et al*. (2018) studied the micronutrient status of Saproon valley of Himachal Pradesh and reported that the DTPA extractable Mn content of the soils ranged from 0.25 to 29.04 mg kg^{-1}.

XII. DTPA-extractable copper

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

In soils of Himachal Pradesh, the content of DTPA-Cu ranged from 0.4 to 4.8 mg kg^{-1} having mean value 1.7 mg kg^{-1} (Tripathi *et al.,* 1994).

The soils of Mandi district of Himachal Pradesh were rich in Cu (1.7 to 2.8 mg kg^{-1}) (Mahajan, 2001). About 3 per cent of Indian soils were deficient in available Cu (Singh, 2001). In the soils of Punjab, DTPA-extractable Cu ranged from 0.04 to 2.40 mg kg^{-1} (Sharma *et al.,* 2002).

Nazif *et al.* (2006) conducted a study at district Bhimber (Jammu and Kashmir) and found that the AB-DTPA extractable copper ranged from 0.59 to 4.38 mg kg^{-1} and it was found high in all sites.

In soils of lower Shivalik of Solan district, the average Cu content ranged from 0.30 to 2.80 mg kg^{-1} and decreased with increasing depth (Sharma and Choudhary, 2007).

In Indian soils, the contents of Cu varied from 0.2 to 5.0 mg kg^{-1} (Rattan *et al.*, 2008). A systematic set of geo-referenced soil samples was collected by Sood *et al.* (2009) from the Muktsar district of Punjab and found that the 7 per cent of the total geographical area was deficient in Cu content.

Availability of Cu ranged from 0.76 to 3.06 ppm when agriculture lands of Manipur were characterized for fertility status by Sahoo *et al.* (2010).

Mustafa *et al.* (2011) examined the soils of Kheragarh tehsil of Agra, Uttar Pradesh, India. They revealed that, the available copper content ranged from 0.04 to 0.43 ppm with an average value of 0.48 ppm.

Verma *et al*. (2013) examined the soil fertility status in *Inceptisol* of Malkarauda block in Janjgir district of Chhattisgarh and they reported that the DTPA- extractable Cu content of soil samples varied from 0.2 to 11.1 mg kg^{-1} with an average value of 4.1 mg kg^{-1}.

Chander *et al.* (2014) studied the micronutrient cations status in vegetable growing soils of sub-humid and wet temperate zone of Himachal Pradesh. They reported that in sub-humid zone, the DTPA- extractable Cu ranged between 0.14 to 2.80 mg kg^{-1}, while in Wet-temperate zone it varied between 0.02 to 3.60 mg kg^{-1}. They further found that Solan and Kangra districts were critical for DTPA-Cu.

DTPA-extractable Cu content in soils of most urbanized Raipur area ranged from 205 to 2800 ppm with a mean value of 4.3 ± 0.3 (Patel *et al.*, 2015).

A systematic survey was done by Annepu *et al.* (2017) at mid Himalayan region of Himachal Pradesh and observed 0.9 ppm available Cu. The deficiency of Cu was observed in 36 per cent soils of the study area.

Kakar *et al.* (2018) studied the micronutrient status of Saproon valley of Himachal Pradesh and observed that the DTPA extractable Cu content of the soils varied between 4.18 to 5.33 mg kg^{-1}.

A field experiment was conducted by Kingsley *et al.* (2019) at a hill slope of Ekpri lbami. They found that Cu was rated as medium (0.2 to 2.0 mg kg^{-1}) in all the slope positions.

XIII. DTPA-extractable zinc

Available Zn status of Kullu valley ranged from 0.38 to 6.60 and 0.05 to 0.068 mg kg^{-1} in surface and sub-surface soils with a mean value of 0.52 and 0.34 mg kg^{-1}, respectively (Grewal *et al.*, 1969).

The DTPA- extractable Zn in calcareous soils ranged from 0.34 to 3.42 ppm as reported by Sakal *et al.* (1986). The DTPA- extractable Zn varied from 0.56 to 6.76 mg kg^{-1} in temperate vegetable growing valley soils of Himachal Pradesh (Thakur and Bhandari, 1986).

In high altitude soils of Kashmir Jalali *et al.* (1989) reported that DTPA-extractable Zn varied from 0.35 to 0.65 mg kg^{-1}. They further reported that Benchmark soils of Kashmir were deficient in DTPA extractable zinc.

Due to strong sorption of Zn by organic matter at high altitude soils, lower contents of available Zn was observed than at the low altitude soils of Sikiim (Lahiri and Chakravarti, 1989).

Distribution of micronutrient in the soils of Himachal Pradesh was studied by Tripathi *et al.* (1994) and showed that the available Zn varied from 0.1 to 2.8 mg kg^{-1}, and with increasing depth the content of DTPA extractable Zn decreased coinciding with the distribution pattern of organic carbon in profiles.

Preliminary surveys was carried out by Nazif *et al.* (2006) at district Bhimber (Jammu and Kashmir) and their results showed that the AB-DTPA extractable zinc content ranged from 0.59 to 4.38 mg $kg^{-1}$and it was found high in all the sites.

Sood *et al.* (2009) collected a systematic set of geo-referenced soil samples from the Muktsar district of Punjab and revealed that the 39 per cent of the total geographical area was deficient in Zn.

While characterising the fertility status of agriculture lands of Manipur, Sahoo *et al.* (2010) revealed that the available Zn ranged from 0.58 to 1.52 ppm.

Mustafa *et al.* (2011) examined the soils of Kheragarh tehsil of Agra in Uttar Pradesh, India and reported that the available zinc content ranged from 0.01 to 1.21 ppm with an average value of 0.30 ppm.

A survey was carried out by Doneriya *et al.* (2013) at Marihan block of Mirzapur district. They reported that the DTPA-extractable Zn content ranged from 0.32 to 3.98 mg kg^{-1} with an average value of 1.35 mg kg^{-1}.

The DTPA-extractable Zn content in the soils of various agro ecosystems varied from 0.01 to 100.2 ppm as reported by Kavitha and Sujatha (2015).

Pawar *et al.* (2016) concluded that available zinc in surface soils ranged between 0.99 to 3.34 mg kg^{-1} with an average value of 1.68 mg kg^{-1}.

While evaluating the soil fertility status in Hassan district of Karnataka, Basavaraja *et al.* (2017) found that the DTPA-extractable Zn was deficient in 55.44 per cent soil samples.

Rai and Singh (2018) reported that the DTPA-extractable Zn content in surface soils varied between 0.38 to 3.04 mg kg^{-1} with an average value of 1.08 mg kg^{-1}.

2.2 NUTRIENT CONCENTRATION IN PLANT LEAVES

2.2.1 Macronutrient concentration in Plant leaves

Menzel and Simpson (1990) conducted studies of litchi trees in subtropical region of Australia and they observed that the concentration of nitrogen and phosphorus fall slightly during the initiation of the vegetative flush then increased to maximum in May-July as the flush matured (1.8 per cent N and 0.19 per cent P). Leaf potassium varied greatly, but was normally low during the emergence of the flush and high when the flush matured.

Kunwar and Singh (1993) conducted a nutritional survey in litchi orchards in Doon valley of Garwal hills of Uttaranchal and they reported that, the leaf nutrient content in Rose Scented cultivar of litchi ranged between 0.93 to 2.11 per cent for N, 0.03 to 0.22 per cent for P, 0.55 to 1.30 per cent for K, 0.40 to 0.95 per cent for Ca and 0.24 to 0.60 per cent for Mg.

While studying the seasonal trend of Mg content in leaves of Nagpur Mandrin, Srivastava *et al*. (1994) observed that there was more or less irregular increasing trend of Mg content in leaves till August, nearly constant from September to October and irregular fluctuation thereafter.

A study on the changes in leaf nutrient content of longan from flowering to fruit development was conducted by Chen (1997). He reported that leaf nutrient content for N, P, K and Ca varied from 1.47 to 1.79, 0.11 to 0.19, 0.89 to 1.77 and 0.76 to 1.12 per cent, respectively.

In litchi orchards of North-Eastern Haryana, a nutritional survey was conducted by Joon *et al.* (1997) and they found that the macronutrient element ranged between 1.36 to 2.38 per cent (Nitrogen), 0.180 to 0.310 per cent (Phosphorus), 0.595 to 0.965 per cent (Potassium), 0.20 to 2.85 per cent (Calcium) and 0.07 to 0.40 per cent (Magnesium).

Hundal *et al*. (2005) collected leaf samples from different mango orchards of Punjab in the month of April and stated that the leaves and fruits of high yielding trees had higher contents of N, P, K, Ca and Mg contents than low yielding trees. The leaf N, P, K, Ca and Mg contents were 1.0 to 1.5 per cent, 0.08 to 0.18 per cent, 0.30 to 1.2 per cent, 3.0 to 5.0 per cent and 0.20 to 0.40 per cent, respectively.

In four districts of Himachal Pradesh, a nutritional survey was carried out by Chandel and Rana (2005) in 20 orchards of Kiwi. They observed that during leaf analysis, N was found low to deficient while P and K was in low to optimum level in many areas and other nutrients element was observed as optimum to high in range.

A study on mango in Malihabad region of Uttar Pradesh was conducted by Kumar *et al*. (2012) and they reported that leaf N, P, K, Ca and Mg concentration of mango varied from

0.7 to 1.8, 0.37 to 1.91, 0.10 to 0.76, 1.4 to 4.90 and 1.54 to 2.58 per cent with an average values of 1.14, 1.09, 0.50, 3.21 and 1.92, respectively.

A survey was carried out by Marathe *et al.* (2016) in 347 pomegranate orchard in major pomegranate growing areas of Maharashtra, Karnataka and Andhra Pradesh and they reported that leaf N was in sufficient to high range and varied from 0.42 to 2.74 per cent in majority of the orchards of Maharashtra and Andhra Pradesh while it was low in Karnataka. Leaf P content was deficient in as many orchards of Maharashtra and Andhra Pradesh while it was comparatively better in Karnataka. Leaf K was sufficient in majority of orchards in all the states.

In Mango orchards of Kangra district of Himachal Pradesh, a study on soil fertility and leaf nutrient status of macronutrients were conducted by Sharma *et al.* (2018) and they found that the leaf nitrogen, phosphorus, potassium, calcium, magnesium and sulphur content ranged from 1.12 to 2.24, 0.14 to 0.27, 0.35 to 0.94, 2.20 to 5.14, 0.42 to 1.48 and 0.24 to 0.65 per cent, respectively.

2.2.2 Micronutrient concentration in Plant leaves

The leaf Fe content of three mango cultivars Dashehri, Chausha and Lukhnow safeda was compared by Samra *et al.* (1979) and they observed that there was higher Fe content in fruiting terminals as compared with non-fruiting terminal of Dashehri (241.0 and 216.0 ppm, respectively), Lukhnow safeda (197.0 and 188.0 ppm, respectively) and Chausha (185.0 and 181.0 ppm, respectively).

In Dashehri mango orchard of Himachal Pradesh, the leaf micronutrient viz. Fe, Cu, Zn and Mn content varied from 176.5 to 192.0, 13.5 to 26.2, 27.5 to 38.8 and 68.3 to 79.7 ppm, respectively (Kumar and Rehalia, 2007).

The different mango orchards of Hyderabad district of Pakistan were surveyed by Azhar *et al.* (2007) and observed that Cu, Zn, Mn and Fe content in mango leaves varied from 21.50 to 82.2, 4.5 to 41.1, 11.8 to 86.2 and 27.8 to 521.3 $\mu g\ g^{-1}$, respectively.

The total zinc content in the pomegranate orchards of Bikaner district of Rajasthan varied from 9.25 to 23.0 ppm with a mean value of 18.55 ppm (Singh and Kumar, 2012). Pawar *et al.* (2014) studied the leaf nutrient status of pomegranate orchards in Osmanabad district of Maharashtra and showed that total zinc, copper, manganese and iron content in leaves varied from 20.5 to 29.3, 83.5 to 158.5, 21.5 to 55.4 and 96.0 to 132.4 mg kg^{-1}, respectively.

A nutritional survey was carried out by Marathe *et al*. (2016) in pomegranate orchards in major pomegranate growing states and they revealed that iron and zinc content ranged from 88.0 to 253.4 ppm and 16.6 to 96.0 ppm, respectively. These were in sufficient range in almost all the orchards in all the states, while leaf copper content varied from 80.0 to 94.9 ppm and it was very low in most of the orchards in all the states. Manganese content in the leaves varied from 16.2 to 94.3 ppm and was in lower range in the states of Maharashtra (51.2 per cent) and Andhra Pradesh (70 per cent) while in Karnataka state it was in sufficient to high range in almost all the orchards.

In the main apple producing regions in China, Yuanmao *et al*. (2018) evaluated the soil nutrient status and leaf nutrient diagnosis and found that in Bohai Bay region, the average content of Fe, Mn, Cu and Zn in leaves was 87.98, 124.02, 13.36 and 15.61 mg kg^{-1}, respectively and in Loess Plateau the respective average content were 88.69, 116.39, 10.85 and 15.94 mg kg^{-1}.

2.3 RELATIONSHIP OF SOIL CHARACTERISTICS WITH THE AVAILABLE SOIL AND LEAF NUTRIENT CONTENTS

2.3.1 Relationship of soil characteristics with the available soil nutrient contents

A highly significant (r = 0.68 **) correlation between Sulphate sulphur and organic carbon in the soils of Himachal Pradesh was reported by Tripathi and Singh (1992). They further found a significant decreased in sulphate sulphur with increase in clay (r = -0.44 **) indicating greater retention form of sulphur by clay fraction in soil.

Ramana Murthy and Srivasttava (1994) conducted a study to evaluate the soil fertility status in relation to terrace management at Majhera farm in lower Shivaliks and indicated that available P is positively related to sand content and EC, but is negatively related to silt content. Available K shows positive relationship with organic carbon content and EC but negative relation with silt.

Sharma *et al.* (2008) studied the soils of Amritsar district of Punjab and they observed that, available N was positively and significantly correlated with organic carbon. Available K showed a significantly positive relationship with organic carbon and clay content.

A negative and highly significant relationship of EC with available P in soils of Madhya Pradesh was found by Trivedi *et al.* (2010).

Annepu *et al.* (2017) assessed the soil fertility status of mid Himalayan region of Himachal Pradesh and they observed that there was a strong and positive correlation between available N (r=0.351**) and organic carbon. Available N showed a positive significant correlation with available P (r=0.263**) and positive relation with available K. The available Zn in the soil has significant and negative relationship with pH (r = -0.484**).

Sharma *et al*. (2018) studied the soil fertility and leaf nutrient status of macronutrients in mango orchards of Kangra district of Himachal Pradesh. They reported that the organic carbon content in the surface soils was significantly and positively correlated with available N (r=0.97**) and P (r=0.45**). While in the subsurface layers the organic carbon was found to be positively correlated with soil N (r=0.91**) and P (r=0.46**) which were found to be significant.

2.3.2 Relationship of soil characteristics with the leaf nutrient content

In apple orchards soils of Shimla district, a non-significant but positive correlation of available Cu and Fe in both surface and sub-surface soils was found with their respective contents in leaves (Bhandari, 1973). A significant and positive correlation between soil N and leaf N was revealed by Singh (1987).

In apple orchard of Sirmour district, a positive and significant correlation between soil and leaf concentration of N, P, K and Cu was observed by Sharma (1988). A positive and significant relationship was found between the contents of Cu and Fe in leaves and soils, whereas for Mn such relationship was significant only for surface soils. A statistically, non-significant relationship between soils and leaf K was found (Sharma and Bhandari, 1992).

A positive and highly significant relationship between available N and Mn in both surface and sub-surface soils was observed with their respective contents in leaves (Sharma, 1994). The relationship for P and K was found to be positive but statistically non-significant (Reddy *et al*., 2003).

The soil fertility and leaf nutrient status of macronutrients was assessed by Sharma *et al*. (2018) in mango orchards of Kangra district of Himachal Pradesh. They found that correlation between the soil and leaf analysis values showed a significant and positive relationship for nitrogen, potassium, magnesium and sulphur for both the surface as well as for sub-surface layers. However, positive and highly significant relationship (r= 0.42**) of sulphur.

Chapter-3

MATERIALS AND METHODS

Soil health/quality decline has emerged as a major factor responsible for the stagnation of productivity. 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 present the analytical tools and methods employed to achieve the specific objectives under the following heads:

3.1 General description of the study area
3.2 Selection of litchi orchards
3.3 Collection and preparation of soil samples
3.4 Collection and preparation of leaf samples
3.5 Laboratory studies
3.6 Interpretation of data
3.7 Statistical analysis

3.1 GENERAL DESCRIPTION OF THE STUDY AREA

3.1.1. Geology, location and extent

Kangra district is situated between 31° 21' to 32° 5" N latitude and 75° 47' 55" to 77° 45" E longitude. It is located in the southern mountain of the Himalayas. The entire area of the district is crossed by the variable altitude of the Shivaliks, Dhauladhar and the Himalayas from north-west to south-east. The altitude varies from 500 meters above mean sea level to around 5000 meters above mean sea level. It is enclosed in the north from the district of Chamba and Lahaul Spiti, in the south by Hamirpur and Una, in the east by Mandi and in the west by Pathankot district of Punjab. The total geographical area of Kangra district is 5,739 sq km, equal to 10.31 per cent of the state's area.

3.1.2. Climate

The climate of the district varies considerably from subtropical in low hills, valleys and sub-humid in mid hill to temperate in high hills. The district receives an average annual rainfall of around 2050 mm which increase from about 1000 mm in the southern parts to about 2500 mm in the north-eastern areas. Most of the rain, around 80 per cent is received in the months of June to September. Snowfall is also received in the northern parts around the areas of Dharamshala, Palampur and Baijnath. The average maximum temperature ranges from about 25.0 degree Celsius in northern parts to around 35.0 degree Celsius in southern areas.

3.1.3. Soil

Soils of the district are mainly derived from lesser or outer Himalayas and Shivalik formation. Slate, phyllites, sandstone and quartzite are the important rock types of the lesser Himalayas, while calcareous conglomerates, sandstone, shale and unasserted alluvial deposits are present in the Shivalik formation. The soils in the foothills of Dhauladhar range show well developed, deep, fine texture and both A and B horizons, which are distinctly expressed. In case of the soils of Shivalik formation, shallow to moderately deep profiles with relatively less expressed horizons and coarse to medium texture are found. In other words, climate and topography play a dominant role in determining the soil characteristics.

3.2 SELECTION OF LITCHI ORCHARDS

Forty orchards of uniform age and growth in the major litchi growing areas of district Kangra were randomly selected to fulfill the objectives of the present investigation. Location of the selected sites has been described in table 3.1.

3.3 COLLECTION AND PREPARATION OF SOIL SAMPLES

Composite soil samples were collected from two depths *i.e* 0-15 and 15-30 cm, from the tree basin of 10 trees in the selected litchi orchards.

The soil samples were air dried in shade, grounded with the help of wooden pestle and mortar and passed through a 2 mm sieve. The processed samples were stored in butter paper bags for further laboratory analysis.

Table 3.1 List of sampling sites of litchi orchards of Kangra district of Himachal Pradesh

Sr. No	Litchi Orchards			Location	
	Sampling site		Name of Owner	Latitude	Longitude
	Block	Village			
1	Sulah	Bhadaldevi	Man Singh Orchard	N 32º04′01″	E 76º28′ 32″
2		Sulah	Ajay Singh	N 32º03′16″	E 76º28′ 26″
3		Garla	Iswar Das	N 32º03′09″	E 76º28′ 36″
4		Majehr	Shayam Lal Bihari	N 32º03′43″	E 76º28′ 31″
5		Malog	Gurbachan Singh	N 32º02′49″	E 76º29′ 04″
6	Bhawarna	Guga -Saloh	Parkash Chand	N 32º03′32″	E 76º29′ 19″
7		Bhedu mahadev	Beni Parshad	N 32º03′40″	E 76º29′ 02″
8		Bhawarna	Vikram Chand	N 32º04′14″	E 76º29′ 34″
9		Sehol	Partap Chand	N 32º01′56″	E 76º29′ 24″
10		Bhadguhar	Parkash Chodhary	N 32º04′48″	E 76º29′ 05″
11	Panchrukhi	Saliyana	Khusi Ram Kalotra	N 32º03′52″	E 76º33′ 44″
12		Panchrukhi	Sansar Chand	N 32º02′53″	E 76º33′ 25″
13		Bhuana	Shakti Dev	N 32º03′01″	E 76º33′ 58″
14		Ladoh	Hukam Chand	N 32º03′07″	E 76º33′ 59″
15		Rakar bheri	Tilk Raj	N 32º04′07″	E 76º29′ 05″
16	Nagrota Bagwan	Amtrar	Suresh Upadhya	N 32º04′56″	E 76º20′ 06″
17		Chahri	Pardeep Kumar	N 32º06′53″	E 76º23′ 21″
18		Kaisthwari	Sanjeev Kumar	N 32º06′36″	E 76º22′ 19″
19		Nagrota Bagwan	Amrik Singh	N 32º06′50″	E 76º22′ 10″
20		Hatwas	Mangal Ram	N 32º06′37″	E 76º23′ 49″

Table 3.1. Contd………..

Sr. No	Litchi Orchards			Location	
	Sampling site		Name of Owner	Latitude	Longitude
	Block	Village			
21	Kangra	Ichhi Khas	Amar Chand	N 32°09′09″	E 76°17′ 18″
22		Tikka Patola	Bidhi Chand	N 32°01′29″	E 76°16′ 39″
23		Ghurkari khas	Bhup Singh	N 32°02′49″	E 76°29′ 04″
24		Birta	Jai Ram Chodhary	N 32°13′45″	E 75°52′ 21″
25	Rait	Ansui	Ramesh Chand	N 32°07′59″	E 75°42′ 23″
26		Rait	Iswar Das	N 32°08′56″	E 76° 08′ 50″
27		Sahpur	Tarm Singh	N 32°10′39″	E 75°58′ 40″
28	Baijnath	Chobin	Bidhi Chand Katoch	N 31°58′32″	E 76°40′ 26″
29		Kudail	Rajeev Rana	N 31°58′11″	E 76°40′ 18″
30		Kunsal	Deep Chand	N 31°59′12″	E 76°39′ 58″
31	Fatehpur	Sudran	Balveer Singh	N 32°09′42″	E 75°57′ 01″
32		Patta Jattian	Shusil Kumar Salariya	N 32°12′47″	E 75°55′ 22″
33	Nagrota Surian	Sunher	Mahender Singh	N 32°08′19″	E 76°00′ 53″
34		Thangar	Shashi Kumar	N 32°08′25″	E 76°00′ 53″
35	Nurpur	Jach	Karpal Singh	N 32°16′49″	E 75°51′ 23″
36		Ganoh	Kewal Singh Pathania	N 32°15′59″	E 75°52′ 22″
37	Indora	Nanglail chak	Baldev Singh	N 32°11′12″	E 75°39′ 51″
38		Surjpur	Abhijeet Pathania	N 32°12′07″	E 75°39′ 46″
39	Dharmshala	Mandal	Mukesh Sharma	N 32°09′16″	E 75°18′45″
40	Lambagaon	Lower lambagaon	Janardhan Chand	N 31°53′23″	E 76°33′ 43″

3.4 COLLECTION AND PREPARATION OF LEAF SAMPLES

Representative leaf samples comprising of 60 leaves were collected from 10 randomly selected trees in each selected orchard. Leaf samples were collected from the same tree from where the soil sample was collected. The second pair of leaflets was collected during August to September, 2018 (Bhargava and Chadha, 1988) for leaf analysis in accordance with the procedure recommended by Chapman (1964).

The leaf samples were washed with ordinary water and then wash with 0.1 N HCl followed by washing with distilled water. After washing, the samples were spread on filter paper for air drying and were subsequently put in paper bags for drying in hot air oven at 60± 5ºC for 72 hours (Kenworthy, 1964). The dried samples were grounded in a stainless steel blender and stored in butter paper bags for chemical analysis.

3.5. LABORATORY STUDIES

3.5.1. Soil Analysis

The processed soil samples were analyzed for important physical and chemical properties of soil *viz.*, Bulk density (Mg cm^{-3}), texture, pH, EC (dS m^{-1}), organic carbon (g kg^{-1}), available macro-nutrients: N, P, K and S (kg ha^{-1}), exchangeable Ca and Mg [cmol (p^{+}) kg^{-1}] and DTPA-extractable micro-nutrients: Fe, Cu, Zn and Mn (mg kg^{-1}) by using standard methods (Table 3.2).

Table 3.2 Analytical methods used for soil analysis

Sr. No.	Soil Property	Method Followed	Reference
1	Bulk density	Core sampler methods	Blake and Hairtge (1986)
2	Soil texture	Hydrometer methods	Bouyoucos (1927)
3	Soil pH	Potentiometric method	Jackson (1973)
4	Electrical Conductivity	Conductimetric method	Jackson (1973)
5	Organic carbon	Rapid Titration method	Walkley and Black (1934)
6	Available nitrogen	Alkaline potassium permanganate	Subbiah and Asija (1956)
7	Available phosphorus	Olsen's method	Olsen *et al*. (1954)
8	Available potassium	Flame photometer	Merwin and Peach (1951)
9	Exchangeable calcium	Flame photometer	Sarma *et al*. (1987)
10	Exchangeable magnesium	Atomic absorption spectrophotometer	Sarma *et al*. (1987)
11	Available sulphur	Turbiditeric method	Chesnin and Yien (1950)
12	DTPA-extractable micronutrients	Atomic absorption spectrophotometer	Lindsay and Norvell (1978)

3.5.2. Leaf analysis

The leaf samples were analyzed for nutrients viz. N, P, K, Ca, Mg, S, Fe, Zn, Cu and Mn contents by using standard method given in table 3.3.

Table 3.3 Analytical methods used for plant analysis

Sr. No.	Nutrient	Method Followed	Reference
1	Total nitrogen	Micro-kjeldhal's methods	Jackson (1973)
2	Total phosphorus	Vanado-molybdate yellow colour	Jackson (1973)
3	Total potassium	Flame photometer	Jackson (1967)
4	Total calcium	Flame photometer	Jackson (1967)
5	Total magnesium	Atomic absorption spectrophotometer	Vogel (1978)
6	Total sulphur	Turbiditeric method	Chesnin and Yin (1950)
7	Total Fe, Zn, Cu and Mn	Atomic Absorption spectrophotometer	Vogel (1978)

3.6. INTERPRETATION OF DATA

3.6.1 Soil analysis data

The critical limits of the soil properties were followed for categorizing nutrients and the results were interpreted using these critical limits which are given in table 3.4.

Table 3.4 Critical limits used for interpretation of chemical properties of the soil

Sr. No.	Nutrient element	Soil fertility class			Reference
		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	Anonymous (2015)
3	Available P (kg ha^{-1})	<10.0	10.0-25.0	>25.0	Anonymous (2015)
4	Available K (kg ha^{-1})	<118.0	118.0-260.0	>260.0	Anonymous (2015)
Secondary macronutrient					
Sr. No.	**Nutrient element**	**Deficient**	**Sufficient**		**Reference**
1	Available Ca [cmol (P^+) kg^{-1}]	<1.5	1.5		Anonymous (2015)
2	Available Mg [cmol (p^+) kg^{-1}]	<1.0	1.0		Anonymous (2015)
3	Sulphate sulphur (kg ha^{-1})	<22.5	22.5		Anonymous (2015)
Micronutrients					
Sr. No.	**Nutrient element**	**Low**	**Medium**	**High**	**Reference**
1	Zn (mg kg^{-1})	<1.0	1.0-3.0	>3.0	Lindsay and Norvel (1978)
2	Cu (mg kg^{-1})	<0.3	0.3-0.8	>0.8	Lindsay and Norvel (1978)
3	Fe (mg kg^{-1})	<4.0	4.0-6.0	>6.0	Lindsay and Norvel (1978)
4	Mn (mg kg^{-1})	<1.2	1.2-3.5	>3.5	Lindsay and norvel (1978)

After categorization of the soil samples according to soil fertility class, soil nutrient indices were prepared to represent the available status of each macro and micro-nutrients using the formula given by Parker *et al*. (1951) as indicated below:

$$\mathrm{SNI} = \frac{(\mathrm{NL\ x\ 1}) + (\mathrm{NM\ x\ 2}) + (\mathrm{NH\ x\ 3})}{\mathrm{NT}}$$

Where,

NL = Number of samples falling in low category of nutrient status

NM = Number of sample falling in medium category of nutrient status

NH = Number of sample falling in High category of nutrient status

NT = Total number of samples analyzed for a given nutrient.

A SNI value <1.67, 1.67 to 2.33 and >2.33 indicates low, medium and high nutrient status of soils, respectively (Ramamurthy and Bajaj, 1969).

3.6.2 Plant analysis data

The critical limits of the nutrients for plant samples given in table 3.5 were followed for categorizing and the results were interpreted.

Table 3.5 Critical limits of nutrients for plant samples

Sr. No	Nutrient element	Concentration				Reference
A. (percent)		**Deficient**	**Low**	**Sufficient**	**High**	Raghupathi and Bhargava (1999)
1	N	<0.54	0.54-0.90	0.91-1.66	>1.66	
2	P	<0.09	0.09-0.11	0 .12-0.18	>0.18	
3	K	<0.20	0.20-0.60	0.61-1.59	>1.59	
4	Ca	<0.13	0.13-0.76	0.77-2.02	>2.02	
5	Mg	<0.03	0.03-0.15	0.16-0.42	>0.42	
6	S	<0.10	0.10-0.15	0.16-0.26	>0.26	
B. (ppm)						
7	Fe	<34	34-70	71-214	>214	
8	Mn	<15	15-28	29-89	>89	
9	Zn	<8	8-13	14-72	>72	
10	Cu	<7	7-28	29-72	>72	

3.7 STATISTICAL ANALYSIS

The descriptive statistics viz. ranges, mean, standard error and coefficient of variation were derived for each soil and leaf parameter. Also, the data was subjected to statistical analysis by adopting simple correlation to find out the extent of relationship of soil characteristics with the available soil and leaf nutrient contents.

Chapter-4

RESULTS AND DISCUSSION

The results emerging from the present investigation entitled **"Studies on nutrient status of Litchi (*Litchi chinensis* Sonn.) orchards of Kangra district of Himachal Pradesh"** have been described under the following heads:

4.1 Physico-chemical properties of the soil

4.1.1 Physical properties

4.1.2 Chemical properties

4.1.3 Nutrient Indices of soil

4.2 Nutrient content of leaves

4.2.1 Macronutrient content of leaves

4.2.2 Micronutrient content of leaves

4.2.3 Plant nutrient status

4.3 Relationship of soil characteristics with the available soil and leaf nutrient contents.

4.3.1 Relationship of soil characteristics with the available soil nutrient contents

4.3.2 Relationship of soil characteristics with the leaf nutrient contents

4.1 PHYSICO-CHEMICAL PROPERTIES OF THE SOIL

4.1.1 Physical properties

I. Bulk density

The data depicted in table 4.1 revealed that the bulk density of the surface soil (0 to 15 cm) varied from 1.20 to 1.35 Mg m^{-3} with a mean value of 1.27 Mg m^{-3} and in sub-surface layer it varied from 1.22 to 1.39 Mg m^{-3} with a mean value of 1.31, Mg m^{-3}. The highest values for surface and sub-surface soil were recorded in Rakkar bheri village of Panchrukhi block and lowest values were recorded in Kunsal village of Baijnath block. The CV of 2.97 and 2.94 per cent for bulk density in the surface and sub-surface depths, respectively indicates that it varied spatially. There was increase in bulk density with the increase in soil depth which might be due to lower organic carbon content in sub-surface layer. The result was in the line of the findings of Sharma and Kanwar (2010) who also reported increase in bulk density with increasing depth at Spiti valley of Himachal Pradesh.

Table 4.1 Bulk density (Mg m^{-3}) of the litchi orchards soils of Kangra district

Orchard No.	Block	Village	Bulk density	
			Soil depth (cm)	
			0-15	15-30
1	Sulah	Bhadaldevi	1.22	1.25
2		Sulah	1.28	1.31
3		Garla	1.25	1.29
4		Majehr	1.26	1.31
5		Malog	1.31	1.33
6	Bhawarna	Guga -Saloh	1.26	1.30
7		Bhedu mahadev	1.27	1.32
8		Bhawarna	1.23	1.25
9		Sehol	1.34	1.37
10		Bhadguhar	1.25	1.29
11	Panchrukhi	Saliyana	1.30	1.33
12		Panchrukhi	1.28	1.32
13		Bhuana	1.24	1.27
14		Ladoh	1.31	1.35
15		Rakkar bheri	1.35	1.39
16	Nagrota Bagwan	Amtrar	1.27	1.33
17		Chahri	1.28	1.31
18		Kaisthwari	1.27	1.31
19		Nagrota Bagwan	1.21	1.24
20		Hatwas	1.29	1.33
21	Kangra	Ichhi Khas	1.33	1.35
22		Tikka Patola	1.32	1.34
23		Ghurkari khas	1.25	1.31
24		Birta	1.26	1.33
25	Rait	Ansui	1.29	1.33
26		Rait	1.24	1.29
27		Shahpur	1.23	1.28
28	Baijnath	Chobin	1.29	1.32
29		Kudail	1.26	1.30
30		Kunsal	1.20	1.22
31	Fatehpur	Sudran	1.25	1.30
32		Patta Jattian	1.23	1.26
33	Nagrota Surian	Sunher	1.30	1.34
34		Thangar	1.31	1.34
35	Nurpur	Jach	1.32	1.35
36		Ganoh	1.29	1.34
37	Indora	Nanglail chak	1.21	1.23
38		Surjpur	1.23	1.28
39	Dharmshala	Mandal	1.27	1.30
40	Lambagaon	Lower lambagaon	1.32	1.36
Range			**1.20-1.35**	**1.22-1.39**
Mean			**1.27**	**1.31**
SE±			**0.01**	**0.01**
C.V (%)			**2.97**	**2.94**

II. Soil texture

The data given in table 4.2 revealed that the soil of litchi orchards of Kangra district varied in texture. Sand content in surface layer (0-15 cm) and sub-surface layer (15-30 cm) depths varied from 54 to 75 and 43 to 61 per cent with mean values of 61.70 and 50.98 per cent, respectively. The CV of 8.33 per cent and 9.28 per cent for sand content in both surface and sub-surface depths respectively indicates that it varied spatially. The silt content in surface soil (0-15 cm) and sub-surface (15-30 cm) depths varied from 10 to 31 and 12 to 38 per cent with mean values of 21.80 and 27.45 per cent, respectively. The CV of 22.53 and 18.05 per cent for silt content in surface and sub-surface depths indicates that these varied spatially in both the depths. The clay content in surface layer (0-15 cm) varied from 10 to 23 per cent with mean values of 16.50 per cent and in sub-surface layer (15-30 cm) it varied from 15 to 29 per cent with mean values of 21.58 per cent. The CV of 21.20 per cent and 17.21 per cent for clay content indicates that these varied spatially in both surface and sub-surface depths, respectively.

In overall, eighty per cent of the surface soil samples were found to be sandy loam in texture and remaining twenty per cent were sandy clay loam in texture (Figure 4.1) and this textural class was found in Sulah village of Sulah block, Guga-Saloh and Bhedu Mahadev villages of Bhawarna block, Ladoh village of Panchrukhi block, Kudail village of Baijnath block, Sudran and Patta Jattian villages of Fatehpur block and Sunher village of Nagrota Surian block. Figure 4.2 revealed that 47 per cent of sub-surface soil samples were sandy clay loam in texture, 30 per cent were loam, 13 per cent sandy loam and 10 per cent were clay loam in texture.

The cumulative range data showed that there was a decrease in the percentage of sand and increase in percentage of silt and clay with increase in soil depth, indicating translocation of finer soil particles to lower depths.

The higher clay content in the sub-surface layers was also reported by Gupta and Verma (1992) which may be attributed to downward translocation of clay under higher rainfall conditions and due to development of textural B horizons. The results were in accordance with the findings of Singh (1987), Sharma and Bhandari (1992) and Sharma *et al*. (2018) they also reported higher clay content in sub-surface soils in apple orchards of district Kinnaur, Mandi and mango orchards of Kangra district, respectively.

Table 4.2 Soil texture of the litchi orchards soils of Kangra district

Sr. No	Block	Village	% Sand		% Silt		% Clay		Textural class	
			Soil depth (cm)							
			0-15	15-30	0-15	15-30	0-15	15-30	0-15	15-30
1	Sulah	Bhadaldevi	61	51	23	27	16	22	sl	scl
2		Sulah	55	46	24	27	21	27	scl	scl
3		Garla	59	48	22	28	19	24	sl	l
4		Majehr	62	47	23	29	15	24	sl	l
5		Malog	60	47	23	29	17	24	sl	l
6	Bhawarna	Guga -Saloh	56	52	23	25	21	23	scl	scl
7		Bhedu mahadev	63	51	16	30	21	19	scl	l
8		Bhawarna	60	49	27	31	13	20	sl	l
9		Sehol	54	51	31	25	15	24	sl	scl
10		Bhadguhar	59	55	22	22	19	23	sl	scl
11	Panchrukhi	Saliyana	62	54	21	25	17	21	sl	scl
12		Panchrukhi	61	43	25	30	14	27	sl	cl
13		Bhuana	56	48	28	32	16	20	sl	l
14		Ladoh	59	51	20	30	21	19	scl	l
15		Rakkar bheri	66	55	17	29	17	16	sl	sl
16	Nagrota Bagwan	Amtrar	63	51	26	34	11	15	sl	l
17		Chahri	62	45	22	35	16	20	sl	l
18		Kaisthwari	67	49	23	34	10	17	sl	l
19		Nagrota Bagwan	64	55	25	25	11	20	sl	scl
20		Hatwas	72	50	11	31	17	19	sl	l
21	Kangra	Ichhi Khas	70	45	13	38	17	17	sl	l
22		Tikka Patola	65	43	24	30	11	27	sl	cl
23		Ghurkari khas	75	51	10	25	15	24	sl	scl
24		Birta	67	47	22	26	11	27	sl	scl
25	Rait	Ansui	61	47	22	30	17	23	sl	cl
26		Rait	55	49	30	27	15	24	sl	scl
27		Shahpur	63	50	24	35	13	15	sl	scl
28	Baijnath	Chobin	71	45	10	29	19	26	sl	cl
29		Kudail	59	53	20	28	21	19	scl	scl
30		Kunsal	67	47	15	24	18	29	sl	scl
31	Fatehpur	Sudran	54	53	25	28	21	19	scl	sl
32		Patta Jattian	57	57	22	24	21	19	scl	sl
33	Nagrota Surian	Sunher	56	55	21	23	23	22	scl	scl
34		Thangar	60	58	24	25	16	17	sl	sl
35	Nurpur	Jach	64	60	22	14	14	26	sl	scl
36		Ganoh	57	51	25	25	18	24	sl	scl
37	Indora	Nanglail chak	67	63	18	12	15	25	sl	scl
38		Surjpur	59	53	23	27	18	20	sl	scl
39	Dharmshala	Mandal	64	61	22	23	14	16	sl	sl
40	Lambagaon	Lower lambagaon	56	53	28	27	16	20	sl	scl
Range			**54-75**	**43-61**	**10-31**	**12-38**	**10-23**	**15-29**		
Mean			**61.70**	**50.98**	**21.80**	**27.45**	**16.50**	**21.58**		
SE±			**0.81**	**0.75**	**0.78**	**0.78**	**0.53**	**0.59**		
CV(%)			**8.33**	**9.28**	**22.53**	**18.05**	**20.12**	**17.21**		

sl: Sandy loam, scl: Sandy clay loam, l: Loam, cl: Clay loam

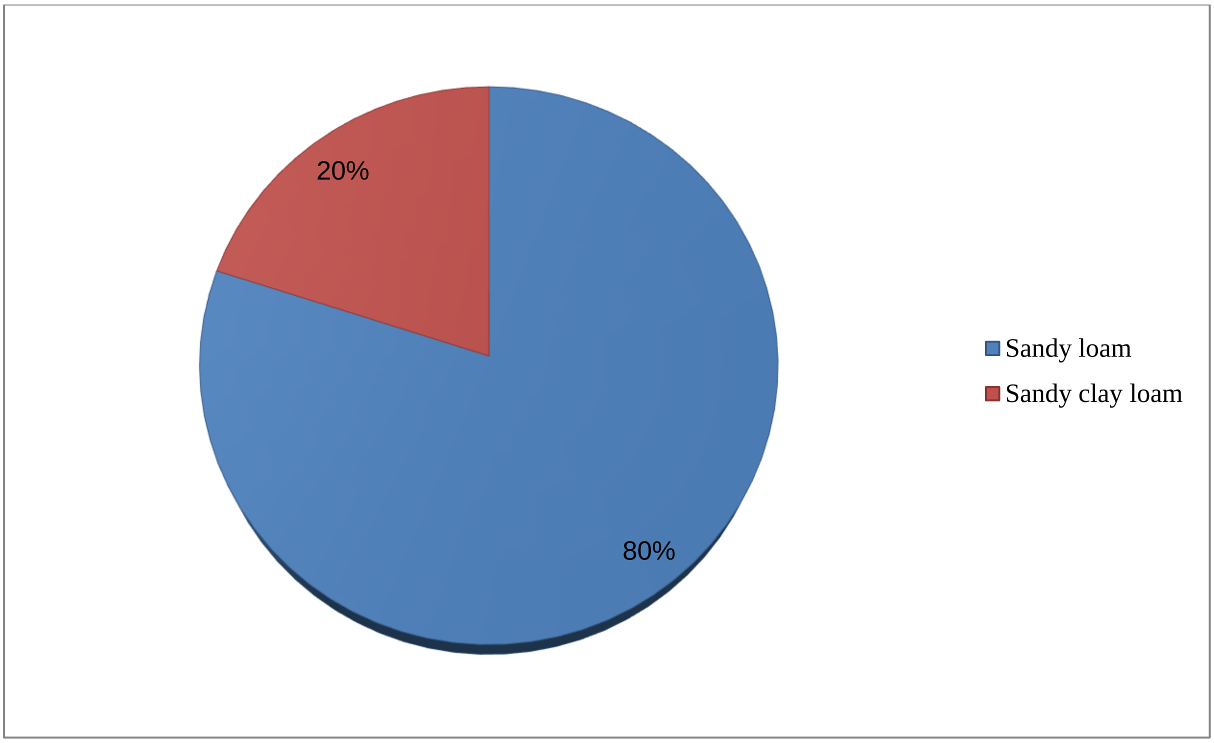

Fig 4.1 Percentage distribution of textural classes in surface soils (0 to 15 cm)

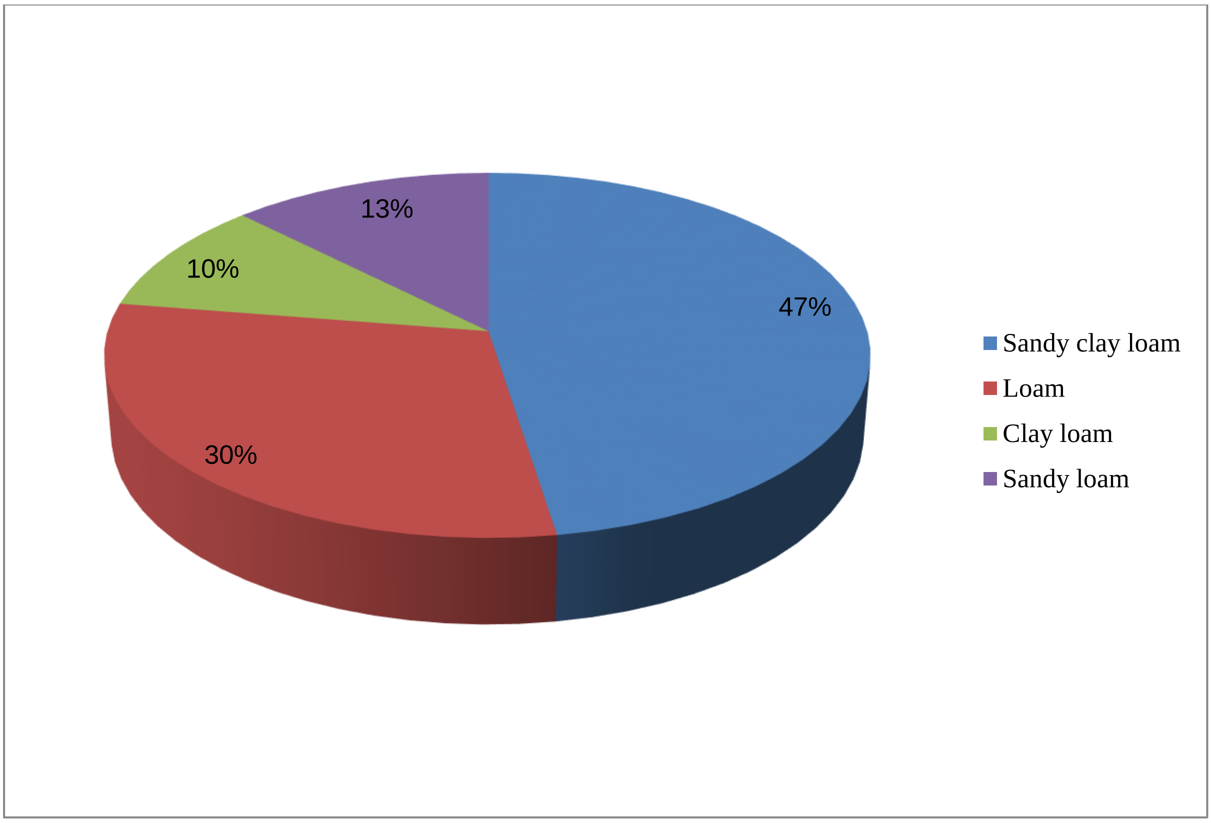

Fig 4.2 Percentage distribution of textural classes in sub-surface soils (15 to 30 cm)

4.1.2 Chemical properties

I. Soil pH

The data presented in table 4.3 revealed that the soil pH in the surface layer (0-15 cm) ranged from 4.65 to 7.49 with a mean value of 5.62 whereas in the sub-surface layer (15-30 cm), it ranged from 4.71 to 7.56 with a mean value of 5.70. The CV of 12.11 per cent and 11.82 per cent for pH indicates that, these varied spatially in both surface and sub-surface depths, respectively. Lowest pH for surface and sub-surface soil was recorded in Panchrukhi village of Panchrukhi block and highest soil pH was recorded in Thangar village of Nagrota Surian block of district Kangra. On comparing different block, higher values of pH were recorded in Nagrota Surian block followed by Nurpur block. In general, most of the soils of litchi orchards of Kangra district were found to be acidic except Nagrota Surian and Nurpur blocks which were found neutral in reaction. For sub-surface layer, soil pH followed similar trend as by the surface layer, however, it increased with increasing depths which might be due to leaching of bases from surface to sub-surface layer (Kaistha *et al.,* 1990, Sahu and Patnaik, 1990 and Walia and Rao, 1996).

The pH of the study area was found to be low which might be due to low degree of base saturation in surface soil. Some soil pH of the study area was found to be near neutral in reaction which corroborates the findings of Kaistha and Gupta (1993) who also observed similar trend in Central Himalayas of Himachal Pradesh.

II. Electrical conductivity (EC)

The perusal of the data in table 4.3 revealed that the electrical conductivity in the surface layer (0-15 cm) ranged from 0.06 to 0.32 dSm^{-1} with a mean value of 0.16 dSm^{-1}. In the sub-surface layer (15-30 cm) the electrical conductivity decreased and it ranged from 0.05 to 0.27 dSm^{-1} with a mean value of 0.14 dSm^{-1}. The highest EC was found in Ganoh village of Nurpur block and lowest was found in Kudail village of Baijnath block of Himachal Pradesh. The CV of 39.77 per cent and 41.41 per cent for EC in both surface and sub-surface depths, respectively indicates that these varied spatially. The result showed that all the electrical conductivity values were under normal range (<1.0). The normal range of the electrical conductivity in the soil is attributed to the leaching of salts to lower depths due to continuous cropping and tillage practices. These results are in agreement with those obtained by Verma and Tripathi (2007) who found that the EC value ranged from 0.01 to 0.15 dSm^{-1} in the soils of mid-Shivalik hills of Himachal Pradesh. However, Bali *et al*. (2010) and Loria *et al*. (2016) found similar normal range of electrical conductivity in agriculture soils of Himachal Pradesh.

Table 4.3 Soil pH and electrical conductivity (dS m^{-1}) of the litchi orchards soils of Kangra district

Orchard No.	Block	Village	pH		EC	
			Soil depth (cm)		Soil depth (cm)	
			0-15	15-30	0-15	15-30
1	Sulah	Bhadaldevi	5.05	5.15	0.17	0.15
2		Sulah	4.89	4.95	0.16	0.14
3		Garla	5.32	5.40	0.12	0.11
4		Majehr	5.16	5.24	0.10	0.08
5		Malog	5.28	5.34	0.11	0.09
6	Bhawarna	Guga -Saloh	5.17	5.24	0.18	0.15
7		Bhedu mahadev	4.82	4.87	0.13	0.11
8		Bhawarna	5.00	5.18	0.16	0.15
9		Sehol	5.40	5.49	0.13	0.12
10		Bhadguhar	5.15	5.25	0.16	0.15
11	Panchrukhi	Saliyana	5.13	5.20	0.13	0.11
12		Panchrukhi	4.65	4.71	0.09	0.08
13		Bhuana	4.78	4.95	0.07	0.06
14		Ladoh	4.97	5.02	0.11	0.09
15		Rakkar bheri	4.89	4.92	0.14	0.13
16	Nagrota Bagwan	Amtrar	5.70	5.74	0.17	0.14
17		Chahri	5.67	5.70	0.13	0.12
18		Kaisthwari	5.97	6.02	0.16	0.15
19		Nagrota Bagwan	5.88	5.93	0.14	0.10
20		Hatwas	5.93	6.00	0.13	0.11
21	Kangra	Ichhi Khas	5.45	5.59	0.19	0.17
22		Tikka Patola	5.69	5.72	0.18	0.15
23		Ghurkari khas	5.76	5.89	0.21	0.19
24		Birta	5.85	5.90	0.18	0.18
25	Rait	Ansui	5.79	5.81	0.16	0.15
26		Rait	5.90	5.92	0.14	0.12
27		Shahpur	5.97	6.18	0.17	0.16
28	Baijnath	Chobin	4.87	4.95	0.08	0.07
29		Kudail	4.95	5.12	0.06	0.05
30		Kunsal	5.21	5.28	0.10	0.07
31	Fatehpur	Sudran	6.18	6.21	0.28	0.25
32		Patta Jattian	6.34	6.41	0.26	0.23
33	Nagrota Surian	Sunher	7.37	7.43	0.24	0.21
34		Thangar	7.49	7.56	0.22	0.19
35	Nurpur	Jach	6.46	6.50	0.25	0.24
36		Ganoh	6.88	6.95	0.32	0.27
37	Indora	Nanglail chak	6.22	6.30	0.29	0.26
38		Surjpur	6.21	6.27	0.27	0.23
39	Dharmshala	Mandal	5.32	5.38	0.07	0.06
40	Lambagaon	Lower lambagaon	6.01	6.14	0.11	0.09
Range			**4.65-7.49**	**4.71-7.56**	**0.06-0.32**	**0.05-0.27**
Mean			**5.62**	**5.70**	**0.16**	**0.14**
SE±			**0.11**	**0.11**	**0.01**	**0.01**
C.V (%)			**12.11**	**11.82**	**39.77**	**41.41**

III. Organic carbon (OC)

The data depicted in table 4.4 revealed that the organic carbon content in the surface layer (0-15 cm) ranged from 9.32 to 22.75 g kg^{-1} with a mean value of 14.60 g kg^{-1}. Whereas, in the sub-surface layer (15-30 cm) it ranged from 8.33 to 21.45 g kg^{-1} with a mean value of 13.45 g kg^{-1}.

Table 4.4 Organic carbon content (g kg^{-1}) of the litchi orchards soils of Kangra district

Orchard No.	Block	Village	Organic carbon Soil depth (cm)	
			0-15	**15-30**
1	Sulah	Bhadaldevi	14.35	12.15
2		Sulah	13.50	11.65
3		Garla	10.12	9.21
4		Majehr	12.21	10.72
5		Malog	13.65	12.75
6	Bhawarna	Guga -Saloh	11.61	10.65
7		Bhedu mahadev	12.64	11.75
8		Bhawarna	13.85	12.14
9		Sehol	12.14	11.23
10		Bhadguhar	11.25	10.45
11	Panchrukhi	Saliyana	14.15	12.05
12		Panchrukhi	13.15	12.42
13		Bhuana	12.25	11.05
14		Ladoh	15.46	14.56
15		Rakkar bheri	13.58	12.75
16	Nagrota Bagwan	Amtrar	12.18	11.23
17		Chahri	15.30	14.25
18		Kaisthwari	13.06	11.95
19		Nagrota Bagwan	14.12	13.45
20		Hatwas	15.21	13.52
21	Kangra	Ichhi Khas	13.42	11.65
22		Tikka Patola	12.46	10.55
23		Ghurkari khas	10.45	9.17
24		Birta	16.85	15.92
25	Rait	Ansui	17.25	16.34
26		Rait	19.45	18.35
27		Shahpur	21.75	20.55
28	Baijnath	Chobin	19.25	18.00
29		Kudail	14.15	12.19
30		Kunsal	16.25	15.00
31	Fatehpur	Sudran	14.22	13.15
32		Patta Jattian	15.95	14.85
33	Nagrota Surian	Sunher	14.65	13.75
34		Thangar	16.18	17.35
35	Nurpur	Jach	15.75	14.15
36		Ganoh	16.25	15.75
37	Indora	Nanglail chak	20.85	19.35
38		Surjpur	22.75	21.45
39	Dharmshala	Mandal	9.32	8.33
40	Lambagaon	Lower lambagaon	13.12	12.33
Range			**9.32-22.75**	**8.33-21.45**
Mean			**14.60**	**13.45**
SE±			**0.48**	**0.49**
C.V (%)			**20.69**	**22.85**

The highest organic carbon content was found in Surjpur village of Indora block and in Mandal village of Dharamshala block lowest organic carbon content was found for surface and sub-surface layers. In all the blocks, the organic carbon followed similar trend in sub-surface layer as by the surface layer, however it decreased with increase in soil depth. The overall results showed that the soils of all the orchards were high in organic carbon content. The CV of 20.69 per cent and 22.85 per cent for organic carbon indicates that, it varied spatially in the surface and sub-surface depths. This may be due to the management practices and variable addition of FYM and plant residues. The results obtained are in accordance with the findings of Sharma *et al*. (2018) who also reported that organic carbon contents were high in most of the soil samples of mango orchards of district Kangra of Himachal Pradesh.

4.1.2.1 Macronutrient status of soil

I. Available Nitrogen (N)

The data on the status of available nitrogen have been enumerated in table 4.5 revealed that the available nitrogen content in the surface layer (0-15 cm) ranged from 273.82 to 395.15 kg ha^{-1} with an average value of 324.97 kg ha^{-1}. Whereas, in the sub-surface layer the available nitrogen content ranged from 264.42 to 372.64 kg ha^{-1} with an average value of 303.20 kg ha^{-1}. The lowest available nitrogen content was found in Mandal village of Dharamshala block and highest content was in Nanglail chak village of Indora block of Himachal Pradesh. For sub-surface layer, available nitrogen followed similar trend as by the surface layer, however, it decreased with increasing depth. The CV of 10.78 per cent and 10.23 per cent for available nitrogen content indicates that, it varied spatially in the surface and sub-surface depths. This may be due to nutrient management practices followed by the farmers of the area and leaching losses of the nitrogen from the soil. Similar results were also reported by Sharma (1988), Raina (1988) and Sharma (1990).

Sharma *et al*. (2018) also reported that most of the soils of Kangra district of Himachal Pradesh were medium in available nitrogen content. Similar results were also reported by Sharma and Kumar (2003) and Pal *et al*. (2013).

II. Available Phosphorus (P)

A perusal of the data presented in table 4.5 revealed that the available phosphorus content in the surface layer (0-15 cm) varied from 22.40 to 60.48 kg ha^{-1} with an average value of 41.33 kg ha^{-1}. While, in the sub-surface layer (15-30 cm) available phosphorus content ranged from 20.14 to 51.52 kg ha^{-1} with an average value of 35.25 kg ha^{-1}. The highest content of available phosphorus was found in Patta Jattian village of Fatehpur block and lowest content of available phosphorus was found in Tikka Patola village of Kangra block.

Table 4.5 Available nitrogen and phosphorus content (kg ha^{-1}) of the litchi orchards soils of Kangra district

Orchard No.	Block	Village	Nitrogen		Phosphorus	
			Soil depth (cm)		Soil depth (cm)	
			0-15	15-30	0-15	15-30
1	Sulah	Bhadaldevi	283.69	267.43	49.28	44.80
2		Sulah	285.86	276.73	31.36	26.88
3		Garla	293.82	284.14	40.32	33.60
4		Majehr	310.41	285.41	35.84	29.12
5		Malog	291.56	278.45	56.00	40.32
6	Bhawarna	Guga -Saloh	361.23	348.58	24.64	22.40
7		Bhedu mahadev	375.62	364.66	42.56	31.36
8		Bhawarna	370.54	345.44	53.76	42.56
9		Sehol	303.05	281.14	49.30	39.10
10		Bhadguhar	325.18	306.22	38.08	34.64
11	Panchrukhi	Saliyana	342.72	317.27	38.08	35.84
12		Panchrukhi	375.20	346.19	47.04	44.80
13		Bhuana	352.40	321.18	33.60	31.36
14		Ladoh	367.24	333.79	26.88	24.60
15		Rakkar bheri	275.73	268.34	50.32	43.60
16	Nagrota Bagwan	Amtrar	284.34	270.58	38.11	33.53
17		Chahri	287.25	272.64	43.70	39.06
18		Kaisthwari	284.36	274.25	52.46	50.02
19		Nagrota Bagwan	315.60	293.74	45.58	42.84
20		Hatwas	287.80	273.73	34.64	28.02
21	Kangra	Ichhi Khas	314.64	286.41	26.78	22.40
22		Tikka Patola	293.56	278.12	22.40	20.14
23		Ghurkari khas	302.14	273.72	26.88	21.60
24		Birta	317.84	276.87	29.13	24.64
25	Rait	Ansui	336.59	295.82	47.04	29.13
26		Rait	356.40	343.86	42.46	35.74
27		Shahpur	394.00	358.06	40.22	33.50
28	Baijnath	Chobin	368.81	342.72	29.12	26.88
29		Kudail	306.23	285.41	25.66	21.20
30		Kunsal	327.28	311.50	23.40	21.16
31	Fatehpur	Sudran	302.17	285.13	58.24	47.04
32		Patta Jattian	327.16	295.92	60.48	51.52
33	Nagrota Surian	Sunher	338.58	318.68	53.76	49.28
34		Thangar	317.87	301.04	56.00	49.30
35	Nurpur	Jach	371.28	327.38	58.24	50.00
36		Ganoh	327.38	304.29	51.52	40.32
37	Indora	Nanglail chak	395.15	372.64	53.76	44.80
38		Surjpur	355.50	321.08	51.52	42.56
39	Dharmshala	Mandal	273.82	264.42	35.74	33.50
40	Lambagaon	Lower lambagaon	298.72	274.83	29.12	26.88
Range			**273.82-395.15**	**264.42-372.64**	**22.40-60.48**	**20.14-51.52**
Mean			**324.97**	**303.20**	**41.33**	**35.25**
SE±			**5.54**	**4.90**	**1.80**	**1.51**
C.V (%)			**10.78**	**10.23**	**27.52**	**27.14**

Similar trend for available phosphorus was followed by the sub-surface layer as by the surface layer, however, it decreased with increasing depths. Available phosphorus content varied spatially in the surface and sub-surface depths as indicated by the respective CVs of 27.52 per cent and 27.14 per cent. The available phosphors content decreased with increasing soil depth was also reported by Dongale (1993). The results obtained are similar to the findings of Sharma *et al*. (2018) who reported that 95 per cent of the soil samples of the mango growing soils of Kangra areas of Himachal Pradesh had high levels of available phosphours content.

III. Available Potassium (K)

The insight of the data in table 4.6 showed that the available potassium in the surface layer (0-15 cm) and sub-surface layer (15-30 cm) varied from 278.09 to 462.58 kg ha^{-1} and 263.51 to 438.17 kg ha^{-1} with a mean values of 367.87 kg ha^{-1} and 339.51 kg ha^{-1}, respectively. The lowest content of available potassium for both surface and sub-surface layer was found in Bhadguhar village of Bhawarna block and highest was found in Kaisthwari village of Nagrota Bagwan block of Kangra district of Himachal Pradesh. The CV of 15.60 per cent and 17.10 per cent for available potassium content indicates that, it varied spatially in the surface and sub-surface depths. The spatial distribution of available potassium may be explained on the basis of pedo-genesis of soils and cumulative effect of nutrient management practices adopted by the litchi growers over the previous years. The available potassium was found to decrease with increase in soil depth, however, it followed similar trend in sub-surface layer as by the surface layer for all the villages. A decrease in potassium content in the sub-surface layer was also reported by Sharma (1988) and Sharma *et al*. (2018).

The overall status of available potassium was high in the litchi orchards. The high content of available potassium in the soils of mango orchards of Kangra district of Himachal Pradesh was also reported by Sharma *et al*. (2018). The findings of Sharma (1990) also support these results who found high available potassium content in apple orchard soils of Mandi district.

IV. Available sulphur

The data depicted in table 4.6 revealed that the available sulphur in surface layer (0-15 cm) ranged from 29.95 to 64.46 kg ha^{-1} with a mean value of 47.59 kg ha^{-1}. Whereas, in the sub-surface layer (15-30 cm) the available sulphur ranged from 23.44 to 61.20 kg ha^{-1}

with a mean value of 39.64 kg ha^{-1}. The lowest available sulphur was found in Kudail village of Baijnath block and highest available sulphur was found in Thangar village of Nagrota Surian block.

Table 4.6 Available potassium and sulphur content (kg ha^{-1}) of the litchi orchards soils of Kangra district

Orchard No.	Block	Village	Potassium		Sulphur	
			Soil depth (cm)		Soil depth (cm)	
			0-15	15-30	0-15	15-30
1	Sulah	Bhadaldevi	309.09	279.17	38.41	26.69
2		Sulah	306.70	289.69	40.37	37.11
3		Garla	302.42	287.12	46.23	39.30
4		Majehr	327.86	319.69	33.86	29.95
5		Malog	285.75	268.19	34.44	27.16
6	Bhawarna	Guga -Saloh	325.44	293.10	51.44	16.93
7		Bhedu mahadev	314.87	300.36	55.34	49.48
8		Bhawarna	323.65	273.23	56.60	54.69
9		Sehol	299.89	282.68	45.58	37.34
10		Bhadguhar	278.09	263.51	59.90	36.46
11	Panchrukhi	Saliyana	297.42	275.60	50.79	30.60
12		Panchrukhi	293.59	269.78	40.37	34.09
13		Bhuana	289.27	274.28	45.39	35.62
14		Ladoh	327.86	319.69	31.90	26.69
15		Rakkar bheri	336.73	332.08	39.06	28.65
16	Nagrota Bagwan	Amtrar	375.46	317.11	54.04	48.83
17		Chahri	417.11	357.10	45.58	36.46
18		Kaisthwari	462.58	438.17	47.30	41.02
19		Nagrota Bagwan	335.11	330.10	48.83	39.06
20		Hatwas	427.57	410.27	56.65	53.39
21	Kangra	Ichhi Khas	441.77	420.86	37.76	29.95
22		Tikka Patola	435.14	415.93	52.09	46.23
23		Ghurkari khas	377.26	311.31	34.51	27.34
24		Birta	356.22	313.04	36.60	25.00
25	Rait	Ansui	438.48	419.01	51.44	43.62
26		Rait	389.58	349.35	63.81	58.60
27		Shahpur	419.79	307.79	51.44	43.62
28	Baijnath	Chobin	323.38	319.69	34.51	28.88
29		Kudail	362.38	256.56	29.95	23.44
30		Kunsal	353.94	346.37	36.46	31.25
31	Fatehpur	Sudran	434.29	411.20	63.16	59.90
32		Patta Jattian	447.70	428.17	43.62	33.20
33	Nagrota Surian	Sunher	442.28	423.85	58.60	57.95
34		Thangar	413.25	404.83	64.46	61.20
35	Nurpur	Jach	418.70	401.40	59.25	50.13
36		Ganoh	435.47	409.74	56.65	54.04
37	Indora	Nanglail chak	404.84	399.34	61.86	57.30
38		Surjpur	443.25	386.53	49.48	42.97
39	Dharmshala	Mandal	391.01	376.38	60.55	55.00
40	Lambagaon	Lower lambagaon	349.73	297.94	35.39	26.62
Range			**278.09-462.58**	**263.51-438.17**	**29.95-64.46**	**23.44-61.20**
Mean			**367.87**	**339.51**	**47.59**	**39.64**
SE±			**9.07**	**9.18**	**1.61**	**1.90**
C.V (%)			**15.60**	**17.10**	**21.39**	**30.29**

In sub-surface layer, available sulphur followed similar trend as by the surface layer, however, it decreased with increasing depths. The CV of 21.39 per cent and 30.29 per cent for available sulphur content indicates that, it varied spatially in the surface and sub-surface depths. Both surface and sub-surface soils were found higher in available sulphur content. The higher content of available sulphur in the soils may be due to the presence of gypsiferrous minerals and ferruginous nature of parent material (Wadia, 1966). Similar trend has also been observed by Jamio (2014) and Sharma *et al*. (2018) for Himachal Pradesh soil**s.**

4.1.2.2 Exchangeable calcium and magnesium

I. Calcium

The data in table 4.7 showed that the exchangeable calcium in surface (0-15 cm) and sub-surface layer (15-30 cm) ranged from 2.75 to 5.31 [cmol (p^+) kg^{-1}] and 2.51 to 4.75 [cmol (p^+) kg^{-1}] with a mean values of 4.07 and 3.64 [cmol (p^+) kg^{-1}], respectively. The highest exchangeable calcium content was found in Sudran village of Fatehpur block and lowest exchangeable calcium content was found in Chobin village of Baijnath block. The CV of 17.99 per cent and 16.95 per cent for exchangeable calcium content indicates that it varied spatially in the surface and sub-surface depths. On comparing different blocks, it was found that Fatehpur, Nagrota Surian, Nurpur and Indora block had higher content of exchangeable calcium as compared to other blocks which might be due to the near neutral pH of the soils. These finding in accordance with the findings of Sharma *et al*. (2002) who also reported that soils of Fatehpur block in Himachal Pradesh were sufficient in calcium. In case of sub-surface layer, exchangeable calcium followed similar trend as by the surface layer, however, it decreased with increasing depths. Sharma *et al*. (2018) also reported higher content of exchangeable calcium which decreased with increasing depth in mango orchards of Kangra district of Himachal Pradesh.

II. Magnesium

The data presented in table 4.7 revealed that the exchangeable magnesium in surface layer (0-15 cm) ranged from 2.00 to 3.59 [cmol (p^+) kg^{-1}] with a mean value of 2.85 [cmol (p^+) kg^{-1}] and in the sub-surface layer (15-30 cm) it ranged from 1.82 to 3.36 [cmol (p^+) kg^{-1}] with a mean value of 2.52 [cmol (p^+) kg^{-1}]. In surface and sub-surface soil, the lowest content of exchangeable magnesium was found in Chobin village of Baijnath block, while highest content of exchangeable magnesium in surface soil was found in Nanglail Chak village of

Indora block and in sub-surface it was highest in Ganoh village of Nurpur block. The CV of 15.47 and 16.45 per cent in surface and sub-surface depth, respectively indicates that available magnesium varied spatially in both the depths.

Table 4.7 Exchangeable calcium and magnesium content [cmol (p^+) kg^{-1}] of the litchi orchards soils of Kangra district

Orchard No.	Block	Village	Calcium		Magnesium	
			Soil depth (cm)		Soil depth (cm)	
			0-15	15-30	0-15	15-30
1	Sulah	Bhadaldevi	4.36	3.06	2.78	2.27
2		Sulah	3.05	2.96	3.23	2.13
3		Garla	4.49	3.04	3.52	2.50
4		Majehr	4.43	3.21	2.43	2.63
5		Malog	3.03	2.87	2.92	2.39
6	Bhawarna	Guga -Saloh	3.00	2.78	2.48	2.19
7		Bhedu mahadev	3.44	3.13	2.33	2.15
8		Bhawarna	3.27	3.17	2.25	2.10
9		Sehol	3.37	3.23	2.38	2.06
10		Bhadguhar	3.66	3.54	2.48	2.09
11	Panchrukhi	Saliyana	4.19	4.00	2.89	2.60
12		Panchrukhi	4.23	3.62	2.26	2.12
13		Bhuana	4.01	3.52	2.32	1.99
14		Ladoh	3.78	3.58	2.85	2.67
15		Rakkar bheri	3.90	3.40	2.81	2.56
16	Nagrota Bagwan	Amtrar	4.60	3.86	2.87	2.72
17		Chahri	3.33	3.29	2.93	2.62
18		Kaisthwari	4.07	4.03	2.99	2.50
19		Nagrota Bagwan	4.32	4.22	2.65	2.48
20		Hatwas	4.46	3.54	3.03	2.64
21	Kangra	Ichhi Khas	4.83	3.46	3.21	3.04
22		Tikka Patola	4.52	4.07	3.16	2.74
23		Ghurkari khas	4.80	4.75	3.22	3.02
24		Birta	4.21	3.91	3.17	3.08
25	Rait	Ansui	4.08	3.44	3.14	2.49
26		Rait	3.96	3.78	2.99	2.62
27		Shahpur	3.14	3.00	2.85	2.77
28	Baijnath	Chobin	2.75	2.51	2.00	1.82
29		Kudail	2.92	2.69	2.02	1.89
30		Kunsal	2.81	2.65	2.17	1.84
31	Fatehpur	Sudran	5.31	4.75	3.40	2.37
32		Patta Jattian	5.25	4.71	3.25	2.46
33	Nagrota Surian	Sunher	5.15	4.60	3.12	3.05
34		Thangar	4.41	4.27	3.26	3.00
35	Nurpur	Jach	4.50	3.85	3.18	3.09
36		Ganoh	4.86	4.25	3.47	3.36
37	Indora	Nanglail chak	5.06	4.46	3.59	3.23
38		Surjpur	4.81	4.12	3.24	2.99
39	Dharmshala	Mandal	3.48	3.21	2.09	1.83
40	Lambagaon	Lower lambagaon	4.82	4.01	2.97	2.69
Range			**2.75-5.31**	**2.51-4.75**	**2.00-3.59**	**1.82-3.36**
Mean			**4.07**	**3.64**	**2.85**	**2.52**
SE±			**0.12**	**0.10**	**0.07**	**0.07**
C.V (%)			**17.99**	**16.95**	**15.47**	**16.45**

The overall status of exchangeable magnesium was found to be high in the litchi growing areas of Kangra district but comparatively higher content was recorded in Fatehpur, Nagrota Surinya, Nurpur and Indora blocks than other blocks. Similar results have been also reported by Sharma *et al*. (2002) reported that the soils of Fatehpur block of Himachal Pradesh were sufficient in magnesium. The exchangeable magnesium content decreased with increasing soil depths, however, it followed similar trend as in surface soil in all the blocks. These results are in conformity with the findings of Sharma *et al*. (2018) who also reported decline in magnesium content with depth in mango orchards of Kangra district.

4.1.2.3 DTPA-extractable micronutrients

I. Iron (Fe)

The DTPA-extractable iron content in surface and sub-surface soils varied from 6.04 to 13.76 mg kg^{-1} and 5.27 to 13.64 mg kg^{-1} with mean values of 9.72 mg kg^{-1} and 9.09 mg kg^{-1}, respectively (Table 4.8). In surface soil the highest contents of iron was observed in Bhawarna village of Bhawarna block and lowest content of iron was observed in Ganoh village of Nurpur block of Himachal Pradesh. The CV of 22.54 per cent and 23.49 per cent for DTPA-extractable iron in surface and sub-surface soil respectively indicated that DTPA-extractable iron content varied spatially in both surface and sub-surface depths. The surface soils had higher iron content as compared to sub-surface soils, however followed similar trend as by the surface layer. Similar results were reported by Sharma *et al*. (2018) who also observed decline in iron content with depth in mango orchards of Kangra district. Fatehpur, Nagrota Surniya, Nurpur and Indora blocks were found to have lower content of DTPA-extractable iron as compared to other blocks which might be due to conversion of iron to insoluble forms with the increase in pH.

II. Copper (Cu)

The data depicted in table 4.8 revealed that the DTPA-extractable copper content in surface and sub-surface soil ranged from 1.23 to 4.10 mg kg^{-1} and 0.94 to 3.80 mg kg^{-1} with a mean value of 2.43 mg kg^{-1} and 1.81 mg kg^{-1}, respectively. In surface soil the highest content of copper was observed in Chobin village of Baijnath block and lowest contents of copper was observed in Jach village of Nurpur block of Himachal Pradesh. The CV of 36.80 per cent and 42.14 per cent for DTPA-extractable copper in surface and sub-surface soils reflected that it varied spatially in both surface and sub-surface depths. The DTPA-extractable copper content decreased with the increase in depth, however, followed similar trend for all the blocks as by the surface layer.

Table 4.8 DTPA-extractable iron and copper content (mg kg^{-1}) of the litchi orchards soils of Kangra district

Orchard No.	Block	Village	Fe		Cu	
			Soil depth (cm)		Soil depth (cm)	
			0-15	15-30	0-15	15-30
1	Sulah	Bhadaldevi	11.63	10.30	3.27	2.60
2		Sulah	12.04	11.24	3.84	2.92
3		Garla	9.62	9.14	2.30	1.70
4		Majehr	10.84	10.49	2.98	2.24
5		Malog	9.82	8.30	2.48	2.14
6	Bhawarna	Guga -Saloh	10.46	9.54	2.94	2.18
7		Bhedu mahadev	12.48	11.07	3.80	3.20
8		Bhawarna	13.76	13.64	3.80	2.62
9		Sehol	10.54	9.78	2.25	1.36
10		Bhadguhar	11.40	10.75	3.01	2.08
11	Panchrukhi	Saliyana	11.46	10.36	3.04	2.29
12		Panchrukhi	12.26	11.69	3.72	3.25
13		Bhuana	13.64	13.34	3.30	3.00
14		Ladoh	11.79	10.49	3.64	2.48
15		Rakkar bheri	12.24	11.78	3.92	2.62
16	Nagrota Bagwan	Amtrar	9.05	8.72	1.96	1.56
17		Chahri	9.19	8.94	2.18	1.20
18		Kaisthwari	8.24	7.95	1.74	1.52
19		Nagrota Bagwan	8.42	7.82	1.83	1.42
20		Hatwas	8.30	8.01	1.76	1.18
21	Kangra	Ichhi Khas	9.25	8.97	2.20	1.84
22		Tikka Patola	9.16	8.84	1.98	1.07
23		Ghurkari khas	8.93	8.30	1.96	1.45
24		Birta	8.42	7.98	1.92	1.52
25	Rait	Ansui	8.55	8.12	1.96	1.06
26		Rait	8.36	8.80	1.78	1.49
27		Shahpur	8.11	7.60	1.65	1.07
28	Baijnath	Chobin	12.24	11.89	4.10	3.80
29		Kudail	11.79	10.82	3.76	2.61
30		Kunsal	10.34	9.78	2.66	1.55
31	Fatehpur	Sudran	7.21	6.85	1.56	1.12
32		Patta Jattian	6.08	5.37	1.45	1.10
33	Nagrota Surian	Sunher	7.88	6.44	1.37	1.17
34		Thangar	6.49	6.24	1.35	1.10
35	Nurpur	Jach	6.59	6.01	1.23	0.94
36		Ganoh	6.04	5.27	1.36	1.00
37	Indora	Nanglail chak	6.24	5.46	1.48	0.96
38		Surjpur	6.72	6.25	1.50	0.97
39	Dharmshala	Mandal	12.66	11.25	1.61	1.24
40	Lambagaon	Lower lambagaon	10.59	9.90	2.39	1.91
Range			**6.04-13.76**	**5.27-13.64**	**1.23-4.10**	**0.94-3.80**
Mean			**9.72**	**9.09**	**2.43**	**1.81**
SE±			**0.35**	**0.34**	**0.14**	**0.12**
C.V (%)			**22.54**	**23.49**	**36.80**	**42.14**

Similar result was also given by Sharma *et al*. (2018) who reported decline in copper content with depth in mango orchards of Kangra district. The overall status of DTPA-extractable copper was found high in litchi growing areas of Kangra district. These results are in conformity with the findings of Tripathi *et al*. (1994) and Mahajan (2001) they also found high levels DTPA-extractable copper in soils of Himachal Pradesh.

III. Manganese (Mn)

The insight of the data in table 4.9 shows that the DTPA-extractable manganese in the surface layer (0-15 cm) varied from 4.34 to 15.24 mg kg^{-1} with a mean value of 8.64 mg kg^{-1} and in sub-surface layer (15-30 cm) it varied from 3.04 to 14.80 mg kg^{-1} with a mean value 7.47 mg kg^{-1}. The lowest content of DTPA-extractable manganese was found in Nanglail chak village of Indora block and highest content of DTPA-extractable manganese was found in Sulah village of Sulah block. The CV indicated that DTPA-extractable manganese varied spatially in surface and sub-surface depths and the respective values were 34.68 and 43.07 per cent. The DTPA-extractable manganese decreased with increasing in soil depth. These results are in line with the findings of Tripathi *et al*. (1994). Sharma *et al*. (2018) also reported decline in copper content with depths in mango orchards of Kangra district of Himachal Pradesh. In overall, DTPA-extractable manganese content was found high for all the soils of litchi orchards of Kangra district.

IV. Zinc (Zn)

It is evident from the data presented in table 4.9 revealed that the DTPA-extractable Zinc in the surface layer (0-15 cm) varied from 1.21 to 3.60 mg kg^{-1} with a mean value of 2.53 mg kg^{-1} and in sub-surface layer (15-30 cm) it varied from 0.90 to 3.14 mg kg^{-1} with a mean value of 2.05 mg kg^{-1}. Highest content of DTPA-extractable zinc was found in Bhuana village of Panchrukhi block and lowest content was found in Thangar village of Nagrota Surian block. The CV of 29.98 and 38.55 per cent for surface and sub-surface indicated that DTPA-extractable zinc varied spatially in both surface and sub-surface depths. The DTPA-extractable zinc was found to decrease with increasing depth of soil. The results get strength from the findings of Sharma *et al*. (2018) who also found decline in zinc content with increase in depth in mango orchards of Kangra district. The high content of DTPA-extractable zinc in surface layer may be due to higher organic carbon content and more favourable soil reaction. Among different blocks, Fatehpur, Nagrota Surinya, Nurpur and Indora have lower content of DTPA-extractable zinc as compared to the other blocks.

Table 4.9 DTPA-extractable manganese and zinc content (mg kg^{-1}) of the litchi orchards soils of Kangra district

Orchard No.	Block	Village	Mn		Zn	
			Soil depth (cm)		Soil depth (cm)	
			0-15	15-30	0-15	15-30
1	Sulah	Bhadaldevi	11.80	10.24	3.01	2.87
2		Sulah	15.24	14.80	3.34	2.94
3		Garla	10.14	9.91	3.36	3.09
4		Majehr	11.69	10.03	3.27	2.98
5		Malog	10.74	9.48	2.58	1.96
6	Bhawarna	Guga -Saloh	9.00	7.80	2.80	2.46
7		Bhedu mahadev	12.64	11.84	3.46	2.87
8		Bhawarna	10.64	8.94	3.16	2.70
9		Sehol	11.08	10.48	3.30	2.98
10		Bhadguhar	10.02	8.19	3.00	2.32
11	Panchrukhi	Saliyana	10.44	9.58	3.04	2.36
12		Panchrukhi	14.00	13.20	3.56	2.95
13		Bhuana	13.40	12.40	3.60	3.14
14		Ladoh	11.01	10.54	3.18	2.28
15		Rakkar bheri	12.20	11.34	3.39	2.98
16	Nagrota Bagwan	Amtrar	7.15	6.81	2.17	1.87
17		Chahri	7.64	6.76	2.23	1.74
18		Kaisthwari	6.12	4.72	1.92	1.00
19		Nagrota Bagwan	6.51	5.29	2.00	1.66
20		Hatwas	6.44	4.74	1.94	1.12
21	Kangra	Ichhi Khas	7.72	6.22	2.24	1.78
22		Tikka Patola	7.60	7.02	2.19	1.85
23		Ghurkari khas	7.04	6.30	2.16	1.94
24		Birta	6.71	5.44	2.12	1.55
25	Rait	Ansui	6.96	5.30	2.14	1.77
26		Rait	6.49	5.40	1.99	1.14
27		Shahpur	5.95	3.82	1.84	1.20
28	Baijnath	Chobin	12.21	11.47	3.40	3.10
29		Kudail	11.34	9.80	3.31	2.73
30		Kunsal	10.96	9.63	3.36	3.14
31	Fatehpur	Sudran	5.79	4.84	1.74	1.09
32		Patta Jattian	4.72	3.26	1.54	1.05
33	Nagrota Surian	Sunher	4.85	3.25	1.30	1.08
34		Thangar	4.79	3.46	1.21	0.90
35	Nurpur	Jach	5.40	3.40	1.45	1.10
36		Ganoh	4.92	3.36	1.30	1.00
37	Indora	Nanglail chak	4.34	3.04	1.68	1.12
38		Surjpur	5.60	4.24	1.73	1.15
39	Dharmshala	Mandal	5.85	4.35	3.48	3.02
40	Lambagaon	Lower lambagaon	8.52	7.93	2.76	2.21
Range			**4.34-15.24**	**3.04-14.80**	**1.21-3.60**	**0.90-3.14**
Mean			**8.64**	**7.47**	**2.53**	**2.05**
SE±			**0.47**	**0.51**	**0.12**	**0.13**
C.V (%)			**34.68**	**43.07**	**29.98**	**38.55**

4.1.3. Nutrient indices of soil

I. Nutrient indices of surface soil

The data presented in table 4.10 represents nutrient indices of surface soils of litchi orchards of Kangra district which reveals that the status of nitrogen was found low in 5.0 per cent samples and the rest of the samples (95 per cent) were under medium category. Overall status of nitrogen was found medium for the litchi orchards of Kangra district. All other nutrients were high in status. The nutrient index values for nitrogen, phosphorus, potassium, sulphur, calcium, magnesium, iron, copper, manganese and zinc were 1.95, 2.90, 3.00, 3.00, 3.00, 3.00, 3.00, 3.00, 3.00 and 2.40, respectively.

Table 4.10 Nutrient indices of surface soils of the litchi orchards of Kangra district

Nutrient	Percentage of samples under each category			Nutrient Index	Nutrient Status
	Low	Medium	High		
N	5	95	-	1.95	Medium
P	-	10	90	2.90	High
K	-	-	100	3.00	High
S	-	-	100	3.00	High
Ca	-	-	100	3.00	High
Mg	-	-	100	3.00	High
Fe	-	-	100	3.00	High
Cu	-	-	100	3.00	High
Mn	-	-	100	3.00	High
Zn	-	60	40	2.40	High

II. Nutrient indices of sub-surface soil

The data depicted in table 4.11 for sub-surface soils showed that nitrogen was low in 32.5 per cent samples and zinc was low in 2.5 per cent samples, however, 67.5, 20, 15 and 85 samples were fell under medium category for nitrogen, phosphorus, manganese and zinc, respectively. All the samples fell in high category for potassium, sulphur, calcium, magnesium, iron and copper. The nutrient index values for nitrogen, phosphorus, potassium, sulphur, calcium, magnesium, iron, copper, manganese and zinc were 1.67, 2.80, 3.00, 3.00, 3.00, 3.00, 3.00, 3.00, 2.85 and 2.10, respectively. The overall status of the litchi orchards of Kangra district was found medium for nitrogen and zinc and rest of the nutrient were found high.

Table 4.11 Nutrient indices of sub-surface soils of the litchi orchards of Kangra district

Nutrient	Percentage of samples under each category			Nutrient Index	Nutrient Status
	Low	Medium	High		
N	32.5	67.5	-	1.67	Medium
P	-	20	80	2.80	High
K	-	-	100	3.00	High
S	-	-	100	3.00	High
Ca	-	-	100	3.00	High
Mg	-	-	100	3.00	High
Fe	-	-	100	3.00	High
Cu	-	-	100	3.00	High
Mn	-	15	85	2.85	High
Zn	2.5	85	12.5	2.10	Medium

4.2 NUTRIENT CONTENT OF LEAVES

4.2.1 Macronutrient content of leaves

I. Primary nutrient content

The data presented in table 4.12 revealed that the leaf nitrogen content in the litchi orchards of Kangra district of Himachal Pradesh varied from 1.21 to 1.56 per cent with a mean value of 1.36 per cent. The highest leaf nitrogen content was found in Bhuana village of Panchrukhi block and lowest content of leaf nitrogen was found in Kunsal village of Baijnath block of Himachal Pradesh. The CV of 6.24 per cent for leaf nitrogen indicates that it varied spatially. The concentration of leaf nitrogen was found sufficient in all the litchi orchards of Kangra district.

Leaf phosphorus content in the litchi orchards of Kangra district of Himachal Pradesh ranged from 0.12 to 0.18 per cent with a mean value of 0.14 per cent (Table 4.12). The CV of 13.39 per cent for leaf phosphorus indicates that it varied spatially. In all the orchards, leaf phosphorus content was found sufficient. The overall status of leaf phosphorus in the litchi orchards was medium in range.

Table 4.12 showed the leaf potassium content in the litchi orchards of Kangra district ranged from 0.81 to 1.44 per cent with a mean value of 1.12 per cent. The lowest content of leaf potassium was found in Malog village of Sulah block and highest was found in Jach village of Nurpur block. The CV for leaf potassium was 16.31 per cent which showed that it varied spatially. Like nitrogen and phosphorus, leaf potassium content was also found sufficient in all the litchi orchards of Kangra district.

Table 4.12 Leaf N, P and K content (per cent) in litchi orchards of Kangra district of Himachal Pradesh

Orchard No.	Block	Village	N	P	K
1	Sulah	Bhadaldevi	1.36	0.15	0.98
2		Sulah	1.26	0.14	1.12
3		Garla	1.28	0.16	1.05
4		Majehr	1.24	0.15	0.97
5		Malog	1.34	0.15	0.81
6	Bhawarna	Guga -Saloh	1.46	0.13	0.99
7		Bhedu mahadev	1.36	0.12	1.21
8		Bhawarna	1.28	0.13	1.13
9		Sehol	1.40	0.18	0.95
10		Bhadguhar	1.50	0.16	0.85
11	Panchrukhi	Saliyana	1.40	0.18	0.90
12		Panchrukhi	1.52	0.14	0.85
13		Bhuana	1.56	0.12	0.93
14		Ladoh	1.42	0.12	0.96
15		Rakkar bheri	1.23	0.16	1.04
16	Nagrota Bagwan	Amtrar	1.29	0.17	0.92
17		Chahri	1.34	0.14	1.29
18		Kaisthwari	1.28	0.15	1.37
19		Nagrota Bagwan	1.36	0.15	0.98
20		Hatwas	1.30	0.12	1.31
21	Kangra	Ichhi Khas	1.32	0.14	1.33
22		Tikka Patola	1.30	0.13	1.28
23		Ghurkari khas	1.29	0.12	1.14
24		Birta	1.32	0.13	1.02
25	Rait	Ansui	1.42	0.15	0.98
26		Rait	1.49	0.12	1.00
27		Shahpur	1.36	0.15	1.36
28	Baijnath	Chobin	1.26	0.13	1.21
29		Kudail	1.37	0.14	1.18
30		Kunsal	1.21	0.12	1.07
31	Fatehpur	Sudran	1.41	0.13	1.41
32		Patta Jattian	1.48	0.18	1.38
33	Nagrota Surian	Sunher	1.43	0.17	1.43
34		Thangar	1.39	0.17	1.26
35	Nurpur	Jach	1.46	0.18	1.44
36		Ganoh	1.32	0.14	1.32
37	Indora	Nanglail chak	1.42	0.15	1.23
38		Surjpur	1.37	0.16	1.29
39	Dharmshala	Mandal	1.28	0.12	0.97
40	Lambagaon	Lower lambagaon	1.34	0.13	1.05
	Range		**1.21-1.56**	**0.12-0.18**	**0.81-1.44**
	Mean		**1.36**	**0.14**	**1.12**
	SE±		**0.01**	**0.01**	**0.03**
	C.V (%)		**6.24**	**13.39**	**16.31**

The sufficient concentration of leaf nitrogen, phosphorus and potassium in the litchi orchards of Kangra district may be ascribed to the medium availability of nitrogen and high availability of phosphorus and potassium in these soils to the plants. Similar findings were given by Kotur and Singh (1994) who also reported sufficient content of these nutrients in litchi orchards of Ranchi. Sharma *et al*. (2018) also observed sufficient content of N, P and K in mango orchards of Kangra district of Himachal Pradesh.

II. Secondary nutrient content of leaves

The leaf sulphur content of litchi orchards ranged from 0.17 to 0.29 per cent with a mean value of 0.24 per cent (Table 4.13). Highest content of leaf sulphur was observed in Jach village of Nurpur block, Surjpur village of Indora block, Thangar village of Nagrota Surian block and Bhadguhar village of Bhawarna block, and lowest content of leaf sulphur was observed in Bhawarna village of Bhawarna block. The CV for leaf sulphur was 12.90 per cent which indicated that it varied spatially. The overall status of leaf sulphur was high.

The data depicted in 4.13 revealed that the leaf calcium content varied from 1.26 to 1.52 per cent with a mean value of 1.40 per cent. The lowest content of leaf calcium was found in Chobin village of Baijnath block and highest content of leaf calcium was found in Sunher village of Nagrota Surian block. The CV of 4.89 per cent showed that leaf calcium content varied spatially. The concentration of leaf calcium was found sufficient in all the litchi orchards of Kangra district of Himachal Pradesh.

The leaf magnesium content in the litchi orchards of Kangra district of Himachal Pradesh ranged from 0.16 to 0.33 per cent with a mean value of 0.26 per cent given in the table 4.13. Highest content of leaf magnesium was found in Patta Jattian village of Fatehpur block and lowest content of leaf magnesium was found in the Kunsal village of the Baijnath block. The CV for leaf magnesium was 16.55 per cent and it varied spatially. The concentration of leaf magnesium was sufficient in all the litchi orchards of Kangra district of Himachal Pradesh.

The observations are in agreement with those of Joon *et al*. (1997) who observed that calcium and magnesium varied from 0.20-2.85 and 0.07 to 0.40 per cent, respectively in litchi orchards of North-Eastern Haryana. Kumar and Rehalia (2007) and Sharma *et al*. (2018) also observed medium concentration of sulphur, calcium and magnesium in mango leaves of mango orchards of Kangra district of Himachal Pradesh.

Table 4.13 Leaf S, Ca and Mg content (per cent) in litchi orchards of Kangra district of Himachal Pradesh

Orchard No.	Block	Village	S	Ca	Mg
1	Sulah	Bhadaldevi	0.27	1.42	0.25
2		Sulah	0.24	1.31	0.30
3		Garla	0.28	1.42	0.23
4		Majehr	0.19	1.44	0.22
5		Malog	0.22	1.32	0.26
6	Bhawarna	Guga -Saloh	0.26	1.30	0.22
7		Bhedu mahadev	0.24	1.33	0.21
8		Bhawarna	0.17	1.31	0.20
9		Sehol	0.23	1.32	0.21
10		Bhadguhar	0.29	1.35	0.22
11	Panchrukhi	Saliyana	0.26	1.40	0.26
12		Panchrukhi	0.28	1.41	0.20
13		Bhuana	0.24	1.39	0.21
14		Ladoh	0.21	1.36	0.26
15		Rakkar bheri	0.27	1.38	0.26
16	Nagrota Bagwan	Amtrar	0.20	1.45	0.25
17		Chahri	0.23	1.32	0.27
18		Kaisthwari	0.25	1.39	0.29
19		Nagrota Bagwan	0.22	1.42	0.24
20		Hatwas	0.19	1.43	0.28
21	Kangra	Ichhi Khas	0.26	1.47	0.30
22		Tikka Patola	0.24	1.44	0.29
23		Ghurkari khas	0.27	1.46	0.30
24		Birta	0.28	1.41	0.28
25	Rait	Ansui	0.21	1.39	0.26
26		Rait	0.28	1.38	0.29
27		Shahpur	0.22	1.30	0.26
28	Baijnath	Chobin	0.20	1.26	0.21
29		Kudail	0.25	1.30	0.18
30		Kunsal	0.22	1.40	0.16
31	Fatehpur	Sudran	0.24	1.51	0.32
32		Patta Jattian	0.22	1.50	0.33
33	Nagrota Surian	Sunher	0.23	1.52	0.29
34		Thangar	0.29	1.45	0.30
35	Nurpur	Jach	0.29	1.47	0.28
36		Ganoh	0.25	1.44	0.32
37	Indora	Nanglail chak	0.25	1.51	0.30
38		Surjpur	0.29	1.46	0.29
39	Dharmshala	Mandal	0.22	1.36	0.19
40	Lambagaon	Lower lambagaon	0.24	1.49	0.27
	Range		**0.17-0.29**	**1.26-1.52**	**0.16-0.33**
	Mean		**0.24**	**1.40**	**0.26**
	SE±		**0.01**	**0.01**	**0.01**
	C.V (%)		**12.90**	**4.89**	**16.55**

4.2.2 Micronutrient content of leaves

The data depicted in 4.14 revealed that the leaf iron content in the litchi orchards of Kangra district of Himachal Pradesh ranged from 72.40 to 139.80 ppm with a mean value of 101.16 ppm. The lowest content of leaf iron was found in the Patta Jattian village of Fatehpur block and highest content of leaf iron was observed in Bhawarna village of Bhawarna block of Himachal Pradesh. The CV of 19.13 per cent for leaf iron showed that it varied spatially. The concentration of leaf iron was in sufficient range in all the litchi orchards of Kangra district of Himachal Pradesh.

Leaf copper content in the litchi orchards of Kangra district of Himachal Pradseh given in table 4.14 and ranged from 33.20 to 56.60 ppm with a mean value of 44.16 ppm. The highest leaf copper content was found in Bhedu mahadev village of Bhawarna block and lowest leaf copper content was found in the Sunher village of Nagrota Surian block of Himachal Pradesh. The CV for leaf copper was 15.82 which indicated that it varied spatially. The concentration of the leaf copper in the litchi orchards of Kangra district was in sufficient range.

The data presented in table 4.14 revealed that the leaf manganese content ranged from 32.20 to 74.40 ppm in the litchi orchards of Kangra district of Himachal Pradesh with a mean value of 57.50 ppm. The highest content of leaf manganese was found in Majehr village of Sulah block and lowest content of leaf manganese was found in Thangar village of Nagrota Surniya block. The CV of 19.81 per cent for leaf manganese indicates its spatial variation. The concentration of leaf manganese in all the litchi orchards of Kangra district of Himachal Pradesh was in sufficient range.

The leaf zinc content in the litchi orchards of Kangra district ranged from 22.00 to 48.80 ppm with a mean value of 35.08 ppm. The lowest leaf zinc content in the litchi orchards was observed in Sunher village of Nagorta Surniya block and highest content of leaf zinc was observed in Bhuana village of Panchrukhi block. The leaf zinc content varied spatially as indicated by the CV of 21.54 per cent. The concentration of leaf zinc was observed sufficient in all the litchi orchards of Kangra district of Himachal Pardesh.

These results are in accordance with the findings of Hundal and Arora (1993), Kunwar and Singh (1993) and Joon *et al*. (1997).

Table 4.14 Leaf Fe, Cu, Mn and Zn content (ppm) in litchi orchards of Kangra district of Himachal Pradesh

Orchard No.	Block	Village	Fe ppm	Cu ppm	Mn ppm	Zn ppm
1	Sulah	Bhadaldevi	118.60	50.40	71.60	41.60
2		Sulah	120.40	52.00	72.20	45.80
3		Garla	96.40	42.60	70.00	47.60
4		Majehr	105.20	48.20	74.40	42.20
5		Malog	98.60	44.40	60.40	36.60
6	Bhawarna	Guga -Saloh	106.40	48.40	61.20	38.60
7		Bhedu mahadev	126.40	56.60	58.00	44.80
8		Bhawarna	139.80	54.60	60.20	40.60
9		Sehol	108.20	42.60	62.20	42.80
10		Bhadguhar	118.40	50.20	70.60	40.00
11	Panchrukhi	Saliyana	116.80	50.20	60.00	39.00
12		Panchrukhi	125.00	56.40	64.80	44.80
13		Bhuana	139.40	52.70	63.40	48.80
14		Ladoh	119.80	54.00	62.80	40.20
15		Rakkar bheri	125.80	53.60	57.60	42.40
16	Nagrota Bagwan	Amtrar	90.60	38.20	51.00	32.20
17		Chahri	93.80	42.40	56.80	34.40
18		Kaisthwari	84.80	36.60	51.80	29.40
19		Nagrota Bagwan	88.20	39.40	55.20	30.40
20		Hatwas	82.00	36.60	54.40	28.80
21	Kangra	Ichhi Khas	95.401	44.00	67.80	34.60
22		Tikka Patola	93.60	39.20	66.40	32.60
23		Ghurkari khas	88.60	37.20	60.80	34.80
24		Birta	86.80	34.40	58.60	32.00
25	Rait	Ansui	87.60	36.40	59.40	30.00
26		Rait	81.40	37.40	54.20	28.60
27		Shahpur	80.80	51.20	49.80	26.40
28	Baijnath	Chobin	125.40	55.20	70.80	42.20
29		Kudail	120.60	44.60	71.60	40.60
30		Kunsal	105.60	38.80	68.80	43.00
31	Fatehpur	Sudran	76.20	45.40	48.60	26.80
32		Patta Jattian	72.40	44.20	38.60	24.00
33	Nagrota Surian	Sunher	88.00	33.20	40.00	22.00
34		Thangar	74.20	35.60	32.20	24.20
35	Nurpur	Jach	76.40	34.20	37.40	26.00
36		Ganoh	80.40	39.40	44.80	23.40
37	Indora	Nanglail chak	82.40	40.20	39.60	25.40
38		Surjpur	87.20	42.60	33.80	28.60
39	Dharmshala	Mandal	128.20	38.40	50.20	36.20
40	Lambagaon	Lower lambagaon	110.60	44.80	68.00	30.80
	Range		**72.40-139.80**	**33.20-56.60**	**32.20-74.40**	**22.00-48.80**
	Mean		**101.16**	**44.16**	**57.50**	**35.08**
	SE±		**3.06**	**1.10**	**1.80**	**1.19**
	C.V (%)		**19.13**	**15.82**	**19.81**	**21.54**

4.2.3 Plant nutrient status

The perusal of the data given in table 4.15 revealed that all the plant nutrients were medium in the leaves of litchi orchards of Kangra district except sulphur which was found medium in 77.5 per cent samples and high in 22.5 per cent samples which may be ascribed to high availability of these nutrients from the soil. These findings are in conformity with the findings of and Kunwar and Singh (1993) and Kotur and Singh (1994).

Table 4.15 Plant nutrient status of litchi orchards of Kangra district

Nutrient	Percent samples		
	Low	Medium	High
N	-	100	-
P	-	100	-
K	-	100	-
S	-	77.5	22.5
Ca	-	100	-
Mg	-	100	-
Fe	-	100	-
Cu	-	100	-
Mn	-	100	-
Zn	-	100	-

4.3 RELATIONSHIP OF SOIL CHARACTERISTICS WITH THE AVAILABLE SOIL AND LEAF NUTRIENT CONTENTS

4.3.1 Relationship of soil characteristics with the available soil nutrient content

The insight of the data depicted in table 4.16 on relationship of surface soil characteristics with the available soil nutrient content revealed that the bulk density had non-significant correlation with all the soils properties. The sand also had non-significant correlation with all the soil properties except silt (-0.783**) and clay (-0.391*) content which showed negative correlation. Silt was significantly correlated only with phosphorus (0.327*), while other soil properties showed non-significant relationship with it. A non-significant relationship of clay was observed with all the soil properties except sand.

Among chemical properties of soils, available nitrogen showed a non-significant relationship with all the soil properties except organic carbon (0.541**). The soil pH was highly positively significantly correlated with available potassium (0.734**) followed by EC

Table 4.16 Relationship among surface soil characteristics

	B.D	Sand	Silt	Clay	pH	EC	OC	N	P	K	S	Ca	Mg	Fe	Cu	Mn	Zn
B.D	1																
Sand	0.003^{NS}	1															
Silt	-0.045^{NS}	-0.783**	1														
Clay	0.062^{NS}	-0.391*	-0.267^{NS}	1													
pH	0.053^{NS}	-0.083^{NS}	0.123^{NS}	-0.054^{NS}	1												
EC	-0.094^{NS}	-0.084^{NS}	0.034^{NS}	0.081^{NS}	0.726**	1											
OC	0.248^{NS}	0.049^{NS}	-0.057^{NS}	0.008^{NS}	0.364*	0.371*	1										
N	-0.259^{NS}	-0.070^{NS}	-0.011^{NS}	0.125^{NS}	0.009^{NS}	0.168^{NS}	0.541**	1									
P	-0.033^{NS}	-0.296^{NS}	0.327*	-0.024^{NS}	0.469**	0.515**	0.246^{NS}	0.098^{NS}	1								
K	0.034^{NS}	0.187^{NS}	-0.124^{NS}	-0.105^{NS}	0.734**	0.601**	0.406**	-0.045^{NS}	0.252^{NS}	1							
S	-0.112^{NS}	-0.205^{NS}	0.272^{NS}	-0.084^{NS}	0.516**	0.479**	0.137^{NS}	0.218^{NS}	0.466**	0.373*	1						
Ca	0.016^{NS}	0.006^{NS}	0.046^{NS}	-0.077^{NS}	0.602**	0.642**	0.044^{NS}	-0.089^{NS}	0.350*	0.494**	0.275^{NS}	1					
Mg	0.103^{NS}	-0.021^{NS}	0.019^{NS}	0.005^{NS}	0.645**	0.738**	0.260^{NS}	-0.126^{NS}	0.332*	0.535**	0.269^{NS}	0.691**	1				
Fe	0.081^{NS}	-0.045^{NS}	-0.018^{NS}	0.096^{NS}	-0.868**	-0.781**	0.480**	-0.037^{NS}	-0.432**	-0.755**	-0.395*	-0.604**	-0.757**	1			
Cu	0.073^{NS}	-0.037^{NS}	-0.147^{NS}	0.275^{NS}	-0.853**	-0.623**	0.261^{NS}	0.102^{NS}	-0.368*	-0.746**	-0.518**	-0.584**	-0.629**	0.878**	1		
Mn	0.104^{NS}	-0.124^{NS}	-0.022^{NS}	0.224^{NS}	-0.862**	-0.673**	0.358*	-0.020^{NS}	-0.352*	-0.823**	-0.555**	-0.567**	-0.582**	0.857**	0.924**	1	
Zn	0.027^{NS}	-0.051^{NS}	-0.046^{NS}	0.147^{NS}	-0.914**	-0.797**	0.466**	-0.067^{NS}	-0.455**	-0.800**	-0.485**	-0.601**	-0.718**	0.932**	0.848**	0.893**	1

NS: Non significant
**Significant at the 0.01 level
* Significant at the 0.05 level

(0.726**) and highest significant negative correlation of soil pH was observed with zinc (-0.914**). The EC was highly significantly positively correlated with exchangeable magnesium (0.738**) followed by exchangeable calcium (0.642**). Highest significant negative correlation of electrical conductivity was observed with DTPA-extractable zinc (-0.797**) followed by DTPA-extractable iron (-0.781**). Organic carbon showed highest significant positive correlation with available nitrogen (0.541**) which may be attributed to the presence of bulk of the total soil nitrogen in organic combination. Similar significant positive correlation of organic carbon content and available nitrogen was observed by Annepu *et al*. (2017) and Sharma *et al*. (2018). Available phosphorus showed highest positive significant correlation with EC (0.515**) followed by soil pH (0.469**) and available sulphur (0.466**). Their existed a highest positive significant relationship of available potassium with soil pH followed by EC than by exchangeable magnesium. All the micronutrients showed significant negative correlation with available potassium, available sulphur, exchangeable calcium and exchangeable magnesium. Highest positive significant correlation of available sulphur, exchangeable calcium and exchangeable magnesium was observed with soil pH (0.516**), exchangeable magnesium (0.691**) and EC (0.738**), respectively. DTPA-extractable micronutrients showed a non-significant correlation with all the physical properties of soil. Among chemical properties of soil, micronutrients showed significant relationship with all properties except available nitrogen. Significant negative correlations of micronutrients were observed with soil pH, EC, available potassium, available sulphur, exchangeable calcium and exchangeable magnesium. Highest positive significant correlation of iron, copper, manganese and zinc was found with DTPA-extractable zinc (0.932**), DTPA-extractable manganese (0.924**), DTPA-extractable copper (0.924**) and DTPA-extractable iron (0.932**), respectively.

Likewise, for sub-surface soils the bulk density showed non-significant correlation with all the soils property (Table 4.17). Sand had highly significant positive correlation with phosphorus (0.486**) and highly significant negative correlation with silt (-0.696**). Silt content was significantly positively correlated with iron (0.393*) followed by manganese (0.338*) and copper (0.317*). Clay was found to have non-significant relationship with all the soil properties except silt content.

Among, the chemical properties of sub-surface soils available nitrogen was found to have non-significant relation with all the soil properties except silt content and organic

Table 4.17 Relationship among sub-surface soil characteristics

	B.D	Sand	Silt	Clay	pH	EC	OC	N	P	K	S	Ca	Mg	Fe	Cu	Mn	Zn
B.D	1																
Sand	-0.116^{NS}	1															
Silt	0.241^{NS}	-0.696**	1														
Clay	-0.133^{NS}	-0.280^{NS}	-0.347*	1													
pH	0.082^{NS}	0.439**	-0.340*	-0.126^{NS}	1												
EC	-0.014^{NS}	0.400*	-0.385*	0.045^{NS}	0.702**	1											
OC	-0.181^{NS}	0.109^{NS}	-0.271^{NS}	-0.009^{NS}	0.438**	0.381*	1										
N	-0.296^{NS}	0.125^{NS}	-0.322*	0.155^{NS}	-0.029^{NS}	0.120^{NS}	0.477**	1									
P	-0.099^{NS}	0.486**	-0.244^{NS}	-0.171^{NS}	0.452**	0.475**	0.241^{NS}	0.090^{NS}	1								
K	0.103^{NS}	0.225^{NS}	-0.073^{NS}	-0.167^{NS}	0.688**	0.581**	0.329*	-0.102^{NS}	0.304^{NS}	1							
S	-0.074^{NS}	0.351*	-0.196^{NS}	-0.162^{NS}	0.567**	0.435**	0.267^{NS}	0.201^{NS}	0.469**	0.537**	1						
Ca	0.060^{NS}	0.428**	-0.221^{NS}	-0.079^{NS}	0.685**	0.669**	0.148^{NS}	-0.074^{NS}	0.442**	0.549**	0.415**	1					
Mg	0.277^{NS}	0.228^{NS}	-0.169^{NS}	-0.016^{NS}	0.708**	0.693**	0.377*	-0.007^{NS}	0.205^{NS}	0.518**	0.279^{NS}	0.649**	1				
Fe	0.006^{NS}	-0.379*	0.393*	-0.001^{NS}	-0.854**	-0.764**	0.439**	0.027^{NS}	-0.397*	-0.692**	-0.387*	-0.637**	-0.730**	1			
Cu	0.032^{NS}	-0.366*	0.317*	0.102^{NS}	-0.778**	-0.592**	0.286^{NS}	0.215^{NS}	-0.258^{NS}	-0.679**	-0.484**	-0.560**	-0.600**	0.819**	1		
Mn	0.083^{NS}	-0.487**	0.338*	0.256^{NS}	-0.852**	-0.662**	0.417**	0.011^{NS}	-0.354*	-0.743**	-0.529**	-0.617**	-0.637**	0.829**	0.871**	1	
Zn	-0.044^{NS}	-0.310^{NS}	0.188^{NS}	0.191^{NS}	-0.845**	-0.724**	0.434**	-0.050^{NS}	-0.417**	-0.709**	-0.502**	-0.696**	-0.736**	0.870**	0.745**	0.869**	1

NS: Non significant
**Significant at the 0.01 level
* Significant at the 0.05 level

carbon content. The further examination of the data showed that the soil pH was highly significantly positively correlated with exchangeable magnesium (0.708**) followed by EC (0.702**), potassium (0.688**), calcium (0.685**), sulphur (0.567**) and phosphorus (0.452 **). Electrical conductivity had highly significant positive correlation with exchangeable magnesium (0.693**) followed by exchangeable calcium (0.669**), available potassium (0.581**), available phosphorus (0.475**) and available sulphur (0.435**). Soil pH and EC had significant negative correlation with all the micronutrients. Soil phosphorus was highly significantly positively correlated with EC (0.475**) among chemical properties of soil. Available potassium was highly significantly positively correlated with soil pH (0.688**) followed by EC (0.581**) calcium (0.549**), sulphur (0.537**) and magnesium (0.518**). Organic carbon content in sub-surface soil showed highest significant positive correlation with available nitrogen (0.477**). Available phosphorus, available potassium, available sulphur, exchangeable calcium and exchangeable magnesium had negative correlation with all the DTPA-extractable micronutrients. The available sulphur was highly significantly positively correlated with soil pH (0.567**) and highly negatively correlated with DTPA-extractable manganese (-0.529**). Calcium was significantly positively correlated with soil pH (0.685**) followed by EC (0.669**), exchangeable magnesium (0.649**). Exchangeable magnesium was highly negatively correlated with zinc (-0.736**), iron (-0.730**), manganese (-0.637**) and with copper (-0.600**).

DTPA-extractable iron was highly positively correlated with zinc (0.870**), manganese (0.829**) and with copper (0.819**). DTPA-extractable copper was highly significantly positively correlated with manganese (0.871**). DTPA-extractable manganese was highly significantly positively correlated with copper (0.871**) and DTPA-extractable zinc was highly significantly correlated with iron (0.870**).

Organic matter is also a major source of micronutrients which stored as constituent of soil organic matter from which they are slowly released by mineralization also metals are made more available to plants as micronutrients are kept in soluble and chelated form. Bhandari and Randhawa (1985) also showed a positive correlation of organic carbon with available micronutrient elements in soils of Himachal Pradesh. Similar results have also been reported by Raina (1988) and Sharma *et al*. (2018) in orchard soils of district Sirmour and district Kangra, respectively.

4.3.2 Relationship of soil characteristics with the leaf nutrient content

The insight of the data depicted in table 4.18 on relationship of surface soil characteristics with the leaf nutrient content revealed that leaf nitrogen was highly significantly negatively correlated with sand content (-0.495**) and highest significant positive correlation was observed with available nitrogen (0.498**). Leaf phosphorus content was highly significantly positively correlated with available phosphorus (0.567**) followed by soil pH (0.354*) and EC (0.340*). Leaf phosphorus was highly negatively significantly correlated with DTPA-extractable iron (-0.357*). Highest significant positive correlation of leaf potassium was noticed with available potassium (0.790**) followed by soil pH (0.610**), EC (0.599**), exchangeable magnesium (0.438**), and exchangeable calcium (0.349*). Leaf sulphur showed significant positive correlation with exchangeable magnesium (0.332*). Leaf calcium was highly significantly positively correlated with exchangeable calcium (0.943**) followed by exchangeable magnesium (0.630**), soil pH (0.623**), EC (0.600**) and soil available potassium (0.498**). Leaf potassium, calcium and magnesium were significantly negatively correlated with all the DTPA-extractable micronutrients. Leaf magnesium was highly positively correlated with exchangeable magnesium (0.895**) followed by EC (0.754**), soil pH (0.671**), exchangeable calcium (0.670**), soil available potassium (0.628**) and phosphorus (0.352*). Highest significant negative correlations of all the micronutrients in litchi leaves were found with soil pH. Leaf iron was highly significantly positively correlated with DTPA-extractable iron (0.972**). Leaf copper was positively correlated with DTPA-extractable copper (0.834**). Leaf manganese was highly significantly positively correlated with DTPA-extractable manganese (0.775**). Leaf zinc was highly significantly positively correlated with DTPA-extractable zinc (0.953**).

Likewise, for sub-surface (Table 4.19) leaf nitrogen showed highest significant positive correlation with available nitrogen (0.450**). Leaf phosphorus was highly significantly positively correlated with available phosphorus (0.590**) followed by sand (0.376*). Leaf potassium was highly positively significantly correlated with available potassium (0.710**) followed by soil pH (0.618**), EC (0.609**), available sulphur (0.435**), exchangeable magnesium (0.432**) and exchangeable calcium (0.370*). Leaf potassium, calcium and magnesium were negatively correlated with all the DTPA-extractable micronutrients. Leaf sulphur was significantly positively correlated with EC (0.321*). Highest significant positive correlation of leaf calcium was noticed with exchangeable

Table 4.18 Relationship of surface soil characteristics with the leaf nutrient content

Soil characteristic	Leaf N	Leaf P	Leaf K	Leaf S	Leaf Ca	Leaf Mg	Leaf Fe	Leaf Cu	Leaf Mn	Leaf Zn
B.D	-0.085^{NS}	0.210^{NS}	0.030^{NS}	0.060^{NS}	-0.034^{NS}	0.180^{NS}	0.066^{NS}	-0.023^{NS}	0.046^{NS}	0.002^{NS}
Sand	-0.495**	-0.221^{NS}	0.159^{NS}	-0.085^{NS}	0.053^{NS}	-0.007^{NS}	-0.092^{NS}	-0.183^{NS}	0.070^{NS}	-0.028^{NS}
Silt	0.382*	0.245^{NS}	-0.261^{NS}	0.066^{NS}	-0.011^{NS}	0.001^{NS}	-0.007^{NS}	-0.010^{NS}	-0.115^{NS}	-0.071^{NS}
Clay	0.202^{NS}	-0.020^{NS}	0.141^{NS}	0.033^{NS}	-0.066^{NS}	0.011^{NS}	0.154^{NS}	0.298^{NS}	0.062^{NS}	0.149^{NS}
pH	0.130^{NS}	0.354*	0.610**	0.169^{NS}	0.623**	0.671**	-0.819**	-0.725**	-0.790**	-0.905**
EC	0.164^{NS}	0.340*	0.599**	0.290^{NS}	0.600**	0.754**	-0.676**	-0.381*	-0.696**	-0.717**
OC	0.127^{NS}	0.076^{NS}	0.376*	0.033^{NS}	-0.069^{NS}	0.316*	-0.407**	-0.095^{NS}	-0.454**	-0.483**
Available N	0.498**	-0.052^{NS}	0.106^{NS}	0.032^{NS}	-0.102^{NS}	-0.117^{NS}	0.047^{NS}	0.310^{NS}	-0.240^{NS}	-0.079^{NS}
Available P	0.273^{NS}	0.567**	0.269^{NS}	0.098^{NS}	0.291^{NS}	0.352*	-0.351*	-0.130^{NS}	-0.658**	-0.435**
Available K	-0.052^{NS}	0.079^{NS}	0.790**	-0.011^{NS}	0.498**	0.628**	-0.737**	-0.633**	-0.644**	-0.824**
Available S	0.323*	0.169^{NS}	0.294^{NS}	0.116^{NS}	0.238^{NS}	0.251^{NS}	-0.355*	-0.321*	-0.627**	-0.504**
Exchang. Ca	0.197^{NS}	0.279^{NS}	0.349*	0.244^{NS}	0.943**	0.670**	-0.552**	-0.409**	-0.466**	-0.568**
Exchang. Mg	0.030^{NS}	0.280^{NS}	0.438**	0.332*	0.630**	0.895**	-0.738**	-0.477**	-0.475**	-0.608**
DTPA- Fe	-0.121^{NS}	-0.357*	-0.591**	-0.226^{NS}	-0.611**	-0.735**	0.972**	0.711**	0.723**	0.873**
DTPA-Cu	-0.109^{NS}	-0.276^{NS}	-0.472**	-0.146^{NS}	-0.610**	-0.591**	0.873**	0.834**	0.715**	0.846**
DTPA-Mn	-0.101^{NS}	-0.207^{NS}	-0.562**	-0.095^{NS}	-0.562**	-0.606**	0.831**	0.759**	0.775**	0.930**
DTPA-Zn	-0.170^{NS}	-0.302^{NS}	-0.639**	-0.157^{NS}	-0.580**	-0.786**	0.905**	0.681**	0.773**	0.953**

NS: Non significant
**Significant at the 0.01 level
* Significant at the 0.05 level

Table 4.19 Relationship of sub-surface soil characteristics with the leaf nutrient content

Soil characteristic	Leaf N	Leaf P	Leaf K	Leaf S	Leaf Ca	Leaf Mg	Leaf Fe	Leaf Cu	Leaf Mn	Leaf Zn
Bulk density	-0.085^{NS}	0.174^{NS}	0.024^{NS}	0.119^{NS}	0.005^{NS}	0.231^{NS}	-0.012^{NS}	-0.063^{NS}	0.011^{NS}	-0.050^{NS}
Sand	0.237^{NS}	0.376*	0.174^{NS}	0.210^{NS}	0.362*	0.180^{NS}	-0.202^{NS}	-0.236^{NS}	-0.628**	-0.423**
Silt	-0.274^{NS}	-0.297^{NS}	-0.090^{NS}	-0.279^{NS}	-0.212^{NS}	-0.052^{NS}	0.228^{NS}	0.260^{NS}	0.374*	0.307^{NS}
Clay	0.016^{NS}	-0.114^{NS}	-0.168^{NS}	0.209^{NS}	0.016^{NS}	-0.072^{NS}	0.014^{NS}	-0.057^{NS}	0.281^{NS}	0.218^{NS}
pH	0.133^{NS}	0.350*	0.618**	0.162^{NS}	0.616**	0.659**	-0.806**	-0.711**	-0.781**	-0.901**
EC	0.179^{NS}	0.357*	0.609**	0.321*	0.569**	0.753**	-0.663**	-0.373*	-0.686**	-0.701**
OC	0.155^{NS}	0.098^{NS}	0.359*	0.066^{NS}	-0.044^{NS}	0.326*	-0.445**	-0.130^{NS}	-0.519**	-0.521**
Available N	0.450**	-0.103^{NS}	0.086^{NS}	0.024^{NS}	-0.174^{NS}	-0.171^{NS}	0.108^{NS}	0.363*	-0.214^{NS}	-0.015^{NS}
Available P	0.304^{NS}	0.590**	0.268^{NS}	0.179^{NS}	0.329*	0.322*	-0.295^{NS}	-0.108^{NS}	-0.654**	-0.412**
Available K	-0.044^{NS}	0.109^{NS}	0.710**	-0.021^{NS}	0.579**	0.625**	-0.684**	-0.616**	-0.631**	-0.746**
Available S	0.097^{NS}	0.072^{NS}	0.435**	-0.074^{NS}	0.328*	0.304^{NS}	-0.383*	-0.380*	-0.636**	-0.529**
Exc-Ca	0.288^{NS}	0.244^{NS}	0.370*	0.246^{NS}	0.801**	0.720**	-0.587**	-0.461**	-0.629**	-0.689**
Exc-Mg	0.009^{NS}	0.266^{NS}	0.432**	0.291^{NS}	0.635**	0.762**	-0.699**	-0.512**	-0.552**	-0.695**
Iron	-0.135^{NS}	-0.386*	-0.571**	-0.224^{NS}	-0.609**	-0.720**	0.940**	0.694**	0.736**	0.867**
Copper	-0.028^{NS}	-0.278^{NS}	-0.445**	-0.092^{NS}	-0.537**	-0.531**	0.833**	0.816**	0.642**	0.790**
Manganese	-0.116^{NS}	-0.212^{NS}	-0.569**	-0.083^{NS}	-0.533**	-0.569**	0.811**	0.740**	0.769**	0.930**
Zinc	-0.232^{NS}	-0.236^{NS}	-0.614**	-0.156^{NS}	-0.520**	-0.790**	0.874**	0.617**	0.764**	0.944**

NS: Non significant

**Significant at the 0.01 level

* Significant at the 0.05 level

calcium (0.801**) followed by exchangeable magnesium (0.635**), soil pH (0.616**), soil available potassium (0.579**) and EC (0.569**). Leaf magnesium was highly positively correlated with exchangeable magnesium (0.762**) followed by EC (0.753**), exchangeable calcium (0.720**), soil pH (0.659**), soil available potassium (0.625**), organic carbon (0.326*) and available phosphorus (0.322*).

Leaf iron, copper, manganese and zinc was highly significantly negatively correlated with soil pH (-0.806**, -0.711**, -0.781** and -0.901**, respectively). Leaf iron, copper, manganese and zinc was highly significantly positively correlated with DTPA-extractable iron (0.940**), DTPA-extractable copper (0.816**), DTPA-extractable manganese (0.769**) and DTPA-extractable zinc (0.944**).

Similar, significant and positive correlations of leaf nutrient content with their respective contents in leaves were also reported by Sharma and Bhandari (1992) and Awasthi *et al*. 1998. Sharma *et al*. (2018) also reported significant and positive relationship for nitrogen, potassium, magnesium and sulphur for both surface as well as sub-surface layers with their respective contents in leaves.

Chapter-5

SUMMARY AND CONCLUSION

Present investigation entitled **"Studies on nutrient status of litchi (Litchi chinensis Sonn.) orchards of Kangra district of Himachal Pradesh"** was carried out during 2018 in major litchi growing areas of Kangra district of Himachal Pradesh with the objective to study the nutritional status of litchi orchards and the relationship of soil characteristics with available soil and leaf nutrient contents.

For this, forty soil sampling sites from litchi growing areas were selected randomly from Kangra districts. Surface (0-15 cm) and sub-surface (15-30 cm) soil samples were collected during the months of October to November, 2018 after the harvesting of litchi fruit and analysed for bulk density, texture, pH, EC, organic carbon, available macro and micronutrient elements. Litchi leaf samples were collected during August to September, 2018 from the litchi growing areas from where the soil samples were collected and analysed for macro and micronutrient elements. The results obtained are summarized as below:

5.1 PHYSICO-CHEMICAL PROPERTIES OF THE SOIL

5.1.1 Physical properties

- The bulk density of the surface soil (0 to 15 cm) varied from 1.20 to 1.35 Mg cm^{-3} with a mean value of 1.27 Mg cm^{-3} and in sub-surface layer it varied from 1.22 to 1.39 Mg cm^{-3} with a mean value of 1.31, Mg cm^{-3} and the highest value was recorded in Rakkar bheri village of Panchrukhi block and lowest value was recorded in Kunsal village of Baijnath block.
- In overall, eighty per cent of the surface soil samples were found to be sandy loam in texture and remaining twenty per cent were sandy clay loam in texture
- 47 per cent of sub-surface soil samples were sandy clay loam in texture, 30 per cent were loam, 13 per cent sandy loam and 10 per cent were clay loam in texture.
- There was a decrease in the percentage of sand and increase in percentage of silt and clay with increase in soil depth, indicating translocation of finer soil particles to lower depths.

5.1.2 Chemical properties

- Most of the soils of litchi orchards of Kangra district were found to be acidic except Nagrota Surian and Nurpur blocks which were found neutral in reaction. For sub-surface layer, soil pH followed similar trend as by the surface layer, however, it increased with increasing depths.
- The electrical conductivity values of all the litchi orchards soils of Kangra district of Himachal Pradesh were under normal range (<1.0).
- The organic carbon content in the surface layer (0-15 cm) ranged from 9.32 to 22.75 g kg^{-1} with the mean value of 14.60 g kg^{-1} whereas; in the sub-surface layer (15-30 cm) it ranged from 8.33 to 21.45 g kg^{-1} with the mean value of 13.45 g kg^{-1}. In all the blocks the organic carbon followed similar trend in sub-surface layer as by the surface layer, however it decreased with increase in soil depth.
- The available nitrogen content in the surface layer (0-15 cm) ranged from 273.82 to 395.15 kg ha^{-1} with an average value of 324.97 kg ha^{-1}. Whereas, in the sub-surface layer the available nitrogen content ranged from 264.25 to 372.64 kg ha^{-1} with an average value of 303.20 kg ha^{-1}. The lowest available nitrogen content was found in Mandal village of Dharamshala block and highest available nitrogen content was found in Nanglail chak village of Indora block of Himachal Pradesh. For sub-surface layer, available nitrogen followed similar trend as by the surface layer, however, it decreased with increasing depths.
- The available phosphorus content in the surface layer (0-15 cm) varied from 22.40 to 60.48 kg ha^{-1} with an average value of 41.33 kg ha^{-1}. While in the sub-surface layer (15-30 cm), the available phosphorus content ranged from 20.14 to 51.52 kg ha^{-1} with an average value of 35.25 kg ha^{-1}. The highest content of available phosphorus was found in Patta Jattian village of Fatehpur block and lowest content of available phosphorus was found in Tikka Patola village of Kangra block.
- The available potassium in the surface layer (0-15 cm) and sub-surface layer (15-30 cm) varied from 278.09 to 462.58 kg ha^{-1} and 263.51 to 438.17 kg ha^{-1} with mean values of 367.87 kg ha^{-1} and 339.51 kg ha^{-1}, respectively. The lowest content of available potassium for both surface and sub-surface layer was found in Bhadguhar village of Bhawarna block and highest was found in Kaisthwari village of Nagrota Bagwan block of Kangra district of Himachal Pradesh.

- The available sulphur in surface layer (0-15 cm) ranged from 29.95 to 64.46 kg ha^{-1} with a mean value of 47.59 kg ha^{-1}. Whereas, in the sub-surface layer (15-30 cm) the available sulphur ranged from 23.44 to 61.20 kg ha^{-1} with a mean value of 39.64 kg ha^{-1}. The lowest available sulphur was found in Kudail village of Baijnath block and highest available sulphur was found in Thangar village of Nagrota Surian block. In sub-surface layer, available sulphur followed similar trend as by the surface layer, however, it decreased with increasing depths.
- The exchangeable calcium in surface (0-15 cm) and sub-surface layer (15-30 cm) ranged from 2.75 to 5.31 [cmol (p^+) kg^{-1}] and 2.51 to 4.75 [cmol (p^+) kg^{-1}] with a mean values of 4.07 and 3.64 [cmol (p^+) kg^{-1}], respectively. The highest exchangeable calcium content was found in Sudran village of Fatehpur block and lowest exchangeable calcium content was found in Chobin village of Baijnath block.
- The exchangeable magnesium in surface layer (0-15 cm) ranged from 2.00 to 3.59 [cmol (p^+) kg^{-1}] with a mean value of 2.85 [cmol (p^+) kg^{-1}] and in the sub-surface layer (15-30 cm) it ranged from 1.82 to 3.36 [cmol (p^+) kg^{-1}] with a mean value of 2.52 [cmol (p^+) kg^{-1}]. In surface and sub-surface soils, the lowest content of exchangeable magnesium was found in Chobin village of Baijnath block, while highest content of exchangeable magnesium in surface soil was found in Nanglail Chak village of Indora block and in sub-surface it was highest in Ganoh village of Nurpur block.
- The DTPA-extractable iron content in surface and subsurface soil varied from 6.04 to 13.76 mg kg^{-1} and 5.24 to 13.64 mg kg^{-1} with a mean value of 9.72 mg kg^{-1} and 9.09 mg kg^{-1}, respectively. In surface and sub-surface soils, the highest contents of iron was observed in Bhawarna village of Bhawarna block and lowest content of iron was observed in Ganoh village of Nurpur block of Himachal Pradesh.
- The DTPA-extractable copper content in surface and sub-surface soil ranged from 1.23 to 4.10 mg kg^{-1} and 0.94 to 3.80 mg kg^{-1} with a mean value of 2.43 mg kg^{-1} and 1.81 mg kg^{-1}, respectively. In surface soil the highest contents of copper was observed in Chobin village of Baijnath block and lowest contents of copper was observed in Jach village of Nurpur block of Himachal Pradesh.
- The DTPA-extractable manganese in the surface layer (0-15 cm) varied from 4.34 to 15.24 mg kg^{-1} with a mean value of 8.64 mg kg^{-1} and in sub-surface layer (15-30 cm) it varied from 3.04 to 14.80 mg kg^{-1} with a mean value 7.47 mg kg^{-1}. The lowest

content of DTPA-extractable manganese was found in Nanglail chak village of Indora block and highest content of DTPA-extractable manganese was observed in Sulah village of Sulah block.

- The DTPA-extractable Zinc in the surface layer (0-15 cm) varied from 1.21 to 3.60 mg kg^{-1} with a mean value of 2.53 mg kg^{-1} and in sub-surface layer (15-30 cm) it varied from 0.90 to 3.14 mg kg^{-1} with a mean value of 2.05 mg kg^{-1}. Highest content of DTPA-extractable zinc was found in Bhuana village of Panchrukhi block and lowest content was found in Thangar village of Nagrota Surian block.

5.1.3 Nutrient Indices of soil

- For surface soils, the status of nitrogen was found low in 5.0 per cent samples and the rest of the samples (95 per cent) were under medium category. Overall status of nitrogen was found medium for the litchi orchards of Kangra district. All other nutrients were high in status.
- Nutrient indices for sub-surface soil showed that nitrogen was low in 32.5 per cent samples and zinc was low in 2.5 per cent samples, however, 67.5, 20, 15 and 85 per cent samples were fell under medium category for nitrogen, phosphorus, manganese and zinc, respectively. All the samples fell in high category for potassium, sulphur, calcium, magnesium, iron and copper.

5.2 NUTRIENT CONTENT OF LEAVES

5.2.1 Macronutrient content of leaves

- The leaf nitrogen content in the litchi orchards of Kangra district of Himachal Pradesh varied from 1.21 to 1.56 per cent with a mean value of 1.36 per cent. The highest leaf nitrogen content was found in Bhuana village of Panchrukhi block and lowest content of leaf nitrogen was found in Kunsal village of Baijnath block of Himachal Pradesh.
- Leaf phosphorus content in the litchi orchards of Kangra district of Himachal Pradesh ranged from 0.12 to 0.18 per cent with a mean value of 0.14 per cent.
- Leaf potassium content in the litchi orchards of Kangra district ranged from 0.81 to 1.44 per cent with a mean value of 1.12 per cent. The lowest content of leaf potassium was found in Malog village of Sulah block and highest was found in Jach village of Nurpur block.

- The leaf sulphur content of litchi orchards ranged from 0.17 to 0.29 per cent with a mean value of 0.24 per cent. Highest content of leaf sulphur was observed in Jach village of Nurpur block and lowest content of leaf sulphur was observed in Bhawarna village of Bhawarna block.
- The leaf calcium content varied from 1.26 to 1.52 per cent with a mean value of 1.40 per cent. The lowest content of leaf calcium was found in Chobin village of Baijnath block and highest content of leaf calcium was found in Sunher village of Nagrota Surian block.
- The leaf magnesium content in the litchi orchards of Kangra district of Himachal Pradesh ranged from 0.16 to 0.33 per cent with a mean value of 0.26 per cent. Highest content of leaf magnesium was found in Patta Jattian village of Fatehpur block and lowest content of leaf magnesium was found in the Kunsal village of the Baijnath block.

5.2.2 Micronutrient content of leaves

- The leaf iron content in the litchi orchards of Kangra district of Himachal Pradesh ranged from 72.40 to 139.80 ppm with a mean value of 101.16 ppm. The lowest content of leaf iron was found in the Patta Jattian village of Fatehpur block and highest content of leaf iron was observed in Bhawarna village of Bhawarna block of Himachal Pradesh.
- Leaf copper content in the litchi orchards of Kangra district of Himachal Pradseh ranged from 33.20 to 56.60 ppm with a mean value of 44.16 ppm. The highest leaf copper content was found in Bhedu mahadev village of Bhawarna block and lowest leaf copper content was found in the Sunher village of Nagrota Surian block of Himachal Pradesh.
- The leaf manganese content ranged from 32.20 to 74.00 ppm in the litchi orchards of Kangra district of Himachal Pradesh with a mean value of 57.50 ppm. The highest content of leaf manganese was found in Majehr village of Sulah block and lowest content of leaf manganese was found in Thangar village of Nagrota Surniya block.
- The leaf zinc content in the litchi orchards of Kangra district ranged from 22.00 to 48.80 ppm with a mean value of 35.08 ppm. The lowest leaf zinc content in the litchi orchards was observed in Sunher village of Nagorta Surniya block and highest content of leaf zinc was observed in Bhuana village of Panchrukhi block.

5.2.3 Plant nutrient status

- All the plant nutrients were medium in the leaves of litchi orchards of Kangra district except sulphur which was found medium in 77.5 per cent samples and high in 22.5 per cent samples.

5.3 RELATIONSHIP OF SOIL CHARACTERISTICS WITH THE AVAILABLE SOIL AND LEAF NUTRIENT CONTENTS

5.3.1 Relationship of soil characteristics with the available soil nutrient content

- The bulk density had non-significant correlation with all the soils property.
- The sand also had non-significant correlation with all the soil properties except silt (-0.783**) and clay (-0.391*) content which showed negative correlation.
- Silt was significantly correlated only with phosphorus (0.327*), while other soil properties showed non-significant relationship with it.
- A non-significant relationship of clay was observed with all the soil properties except sand.
- The soil pH was highly positively significantly correlated with available potassium (0.734**) followed by EC (0.726**) and highest significant negative correlation of soil pH was observed with zinc (-0.914**).
- The EC was highly significantly positively correlated with exchangeable magnesium (0.738**).
- Soil available nitrogen showed a non-significant relationship with all the soil properties except organic carbon.
- Available phosphorus showed highest positive significant correlation with EC (0.515**).
- Their existed a highest positive significant relationship of available potassium with soil pH followed by EC than by exchangeable magnesium.
- All the micronutrients showed significant negative correlation with available potassium, available sulphur, exchangeable calcium and exchangeable magnesium.
- Highest positive significant correlation of available sulphur, exchangeable calcium and exchangeable magnesium was observed with soil pH (0.516**), exchangeable magnesium (0.691**) and EC (0.738**), respectively.
- DTPA-extractable micronutrients showed a non-significant correlation with all the physical properties of soil.

- Significant negative correlations of micronutrients were observed with soil pH, EC, available potassium, available sulphur, exchangeable calcium and exchangeable magnesium.
- Highest positive significant correlation of iron, copper, manganese and zinc was found with DTPA-extractable zinc (0.932**), DTPA-extractable manganese (0.924**), DTPA-extractable copper (0.924**) and DTPA-extractable iron (0.932**), respectively.

5.3.2 Relationship of soil characteristics with the leaf nutrient content

- Leaf nitrogen was highly significantly negatively correlated with sand content (-0.495**) and highest significant positive correlation was observed with available nitrogen (0.498**).
- Leaf phosphorus content was highly significantly positively correlated with available phosphorus (0.567**).
- Leaf phosphorus was highly negatively significantly correlated with DTPA-extractable iron (-0.357*).
- Highest significant positive correlation of leaf potassium was noticed with available potassium (0.790**) followed by soil pH (0.610**), EC (0.599**), exchangeable magnesium (0.438**) and exchangeable calcium (0.349*).
- Leaf sulphur showed significant positive correlation with exchangeable magnesium (0.332*).
- Leaf calcium was highly significantly positively correlated with exchangeable calcium (0.943**) followed by exchangeable magnesium (0.630**), soil pH (0.623**), EC (0.600**) and soil available potassium (0.498**).
- Leaf magnesium was highly positively correlated with exchangeable magnesium (0.895**) followed by EC (0.754**), soil pH (0.671**), exchangeable calcium (0.670**), soil available potassium (0.628**) and phosphorus (0.352*).
- Highest significant negative correlations of all the micronutrients in litchi leaves were found with soil pH. Leaf iron was highly significantly positively correlated with DTPA-extractable iron (0.972**).
- Leaf copper was positively correlated with DTPA-extractable copper (0.834**).
- Leaf manganese was highly significantly positively correlated with DTPA-extractable manganese (0.775**).

- Leaf zinc was highly significantly positively correlated with DTPA-extractable zinc (0.953**).

CONCLUSIONS

From the present study, it is concluded that

The litchi orchard soils of Kangra district were coarser in nature having sandy loam to sandy clay loam texture. Most of the soils were acidic except Nagrota Surian and Nurpur blocks which were neutral in reaction. All the nutrients in soil were found high in status except nitrogen and zinc which were medium in status. Most of the macro and micronutrient contents of litchi leaf were sufficient except sulphur which was high in 22.5 per cent samples.

Bulk density and available nitrogen had non-significant relationship with most of the soil properties. Organic carbon content was positively correlated with all the chemicals properties of the soil. All the DTPA-extractable micronutrients were negatively correlated with soil pH, EC, available P, K & S and exchangeable calcium & magnesium. Highest significant positive correlation of leaf nitrogen, phosphorus, potassium, calcium, magnesium, iron, copper, manganese and zinc was found with their respective availability in soil.

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Department of Soil Science and Water Management
College of Horticulture and Forestry
Dr. Yashwant Singh Parmar University of
Horticulture and Forestry,
Neri-177001, Hamirpur (H.P.)

Title of the Thesis	**:**	**Studies on nutrients status of Litchi (*Litchi chinensis* Sonn.) orchards of Kangra District of Himachal Pradesh**
Name of the Student	**:**	Vishal Chandel
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Major Advisor	**:**	Dr. Anil Kumar

ABSTRACT

Investigation entitled "Studies on nutrient status of Litchi (*Litchi chinensis* Sonn.) orchards of Kangra district of Himachal Pradesh" was undertaken with the objective to study the nutritional status of litchi orchards and the relationship of soil characteristics with available soil and leaf nutrient contents. For this, forty soil sampling sites from litchi growing areas were selected randomly. Surface (0-15 cm) and sub-surface (15-30 cm) soil samples were collected during the months of October to November, 2018 after the harvesting of litchi fruit and analyzed for bulk density, texture, pH, EC, organic carbon, available macro and micronutrients. Litchi leaf samples were collected during August to September, 2018 from where the soil samples were collected and analyzed for all macro and micronutrients. The litchi orchard soils of Kangra district were coarser in nature having sandy loam to sandy clay loam in texture. Most of the soils were acidic except Nagrota Surinya and Nurpur blocks which were neutral in reaction. All the nutrients in soils were found high in status except nitrogen and zinc which were medium in status. Most of the macro and micronutrient contents of litchi leaf were sufficient except sulphur which was high in 22.5 per cent samples. Bulk density had non-significant relationship with most of the soil properties. Organic carbon content was positively correlated with all the chemicals properties of the soil. All the DTPA-extractable micronutrients were negatively correlated with soil pH, EC, available P, K & S and exchangeable Ca & Mg. Highest significant positive correlation of leaf N, P, K, Ca, Mg, Fe, Cu, Mn and Zn was found with their respective availability in soil.

Signature of the Student	**Signature of the Major Advisor**
Name	**Name**
Date	**Date**

Head of the Department

BRIEF BIO-DATA

Name : Vishal Chandel

Father's Name : Sh. Sohan Singh

Mother's Name : Mrs. Satya Devi

Date of Birth : 04.01.1995

Permanent Address : Village Kothi Post office Kharihat (Thara) Tehsil Joginder Nagar District Mandi (HP)-175015

Academic Qualification :

Class	Month and Year	School	Board/ University	Marks	Division
10th	March, 2010	Govt Sr Sec School Langna	HPBOSE	534/700	First
12th	March, 2012	Govt Sr Sec School Langna	HPBOSE	396/500	First
B. Sc. Horticulture (Hons.)	April, 2017	Dr Y.S. Parmar UHF, Nauni, Solan (HP)	Dr Y.S. Parmar UHF, Nauni, Solan (HP)	68.30/10 (OGPA)	First

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(Vishal Chandel)