NUTRITIONAL STATUS OF VEGETABLE GROWING AREAS OF MANDI DISTRICT OF HIMACHAL PRADESH

Thesis

by

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CERTIFICATE- I

This is to certify that the thesis titled **"Nutritional status of vegetable growing areas of Mandi district of Himachal Pradesh"**, submitted in partial fulfillment of the requirements for the award of degree of **MASTER OF SCIENCE (AGRICULTURE)** in the discipline **SOIL SCIENCE** to Dr. Yashwant Singh Parmar University of Horticulture and Forestry, (Nauni) Solan (HP)-173 230 is a bonafide research work carried out by **Mr. Nishant Thakur (NF-2017-04-M)** son of Sh. Rup Lal Thakur 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 investigation has been fully acknowledged.

Place: Neri, Hamirpur
Dated:

Dr. Rakesh Sharma
Major Advisor

CERTIFICATE- II

This is to certify that the thesis titled **"Nutritional status of vegetable growing areas of Mandi district of Himachal Pradesh"**, submitted by **Mr. Nishant Thakur (NF-2017-04-M)** son of Sh. Rup Lal Thakur to the Dr. Yashwant Singh Parmar University of Horticulture and Forestry, (Nauni) Solan (HP)-173 230 India in partial fulfilment of the requirements for the degree of **MASTER OF SCIENCE (AGRICULTURE)** in the discipline of **SOIL SCIENCE** has been approved by the Advisory Committee after an oral examination of the student in collaboration with an external Examiner.

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This is to certify that all the mistakes and errors as pointed out by the external examiner have been incorporated in the thesis titled, **“Nutritional status of vegetable growing areas of Mandi district of Himachal Pradesh”**, submitted by **Mr. Nishant Thakur (NF-2017-04-M)** Son of Sh. Rup Lal Thakur to Dr. Yashwant Singh Parmar University of Horticulture and Forestry, (Nauni) Solan (H.P.) in partial fulfilment of the requirements for the award of degree of **MASTER OF SCIENCE (AGRICULTURE) SOIL SCIENCE**.

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Place: Hamirpur (Neri)

Date: **Nishant Thakur**

CONTENTS

ABBREVIATIONS USED

%	Per cent
BD	Bulk density
Ca	Calcium
$CaCO_3$	Calcium carbonate
CV	Coefficient of variation
cm	Centimeter
cmol (p^+) kg^{-1}	Centimole proton equivalence per kilogram
Cu	Copper
dS m^{-1}	Deci Siemens per meter
DTPA	Dietylene Triamine Penta Acetic Acid
E	East
EC	Electrical conductivity
et al	Co-workers
etc	*et cetera*
Fe	Iron
g	Gram
g kg^{-1}	Gram per kilogram
HCl	Hydrochloric acid
HNO_3	Nitric acid
$HClO_4$	Perchloric acid
H. P.	Himachal Pradesh
ha	Hectare (10,000 m^2)
i.e.	*That is*
ISSS	International Society of Soil Science
K	Potassium
kg ha^{-1}	Kilogram per hectare
me 100^{-1} g	Milliequivalent per hundred gram
mm	Milli meter
m	Meter
Mg	Magnesium
mg kg^{-1}	Milligram per kilogram
ml	Milli liters
Mn	Manganese
N	North
OC	Organic carbon
^oC	Degree Celsius
P	Phosphorus
pH	*Puissance de Hydrogen*
ppm	Parts per million
S	Sulphur
SE	Standard Error
SNI	Soil Nutrient Index
$SnCl_2$	Stannous chloride
S	Sulphur
SSP	Single supper phosphate
viz.	*Videlicet*
w.r.t	With respect to
Zn	Zinc
FYM	Farm yard manure

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INTRODUCTION

Chapter – 1

INTRODUCTION

Pea (*Pisum sativum* L.) is one of the most important commercial vegetable crop which belongs to family leguminosae and is grown in temperate to tropical regions. Pea cultivation is believed to have originated in Central Asia, the Near East, Abyssinia and the Mediterranean from where, it seems to have spread all over the World. It is basically a temperate vegetable crop, but has acclimatized to sub-tropical and tropical agro climatic conditions prevailing in the Indian sub-continent.

It is the second most widely cultivated legume crop of the world (Pawar *et al.* 2017). In India it is cultivated on an area of 554 thousand ha with an annual production of 5524 thousand metric tons with a productivity of 10 metric tons ha^{-1} (Anonymous, 2019). The main pea producing states are Uttar Pradesh, Madhya Pradesh, Punjab, Assam, Himachal Pradesh and West Bengal.

Pea is very common nutritious vegetable grown for both fresh and dried seeds. It can be consumed either fresh, canned, pulse, frozen or in dehydrated forms. It is very rich in protein (7.2 g), vitamin A (139 I.U.) and C (9 mg), calcium (20 mg), phosphorus (139 mg), energy (81 kcal), carbohydrates (14.5 g) and sugars (5.67 g/100g) of edible portion (Peter *et al.* 2012). Green peas contain a high percentage of essential amino acids.

Soil fertility influences yield, quality and production of pea. Peas require adequate supplies of nutrients for growth and development. Nutrient deficiencies affect the quantity and quality of pea. It is the grower's objective to increase the availability of naturally occurring soil nutrients and to supplement deficient nutrients when needed, thus, it is highly indispensable to use the appropriate methods that lead to proper evaluation of the nutritional status of the crop.

Sustainable agricultural productivity is affected by a number of factors *viz*. climate, soil, agricultural input availability, size of land holding, technical know-how, irrigation facilities, population pressure on land, land tenure system etc. Amongst all, soil is the critical component, functioning not only for the production of food, fodder and fiber but also for the maintenance of local, regional and global environmental quality (Pathak, 2010).

Himachal Pradesh is an important hill state in Western Himalayas and is endowed with varied agro-climatic conditions especially, agro-climatic 'niches'. In the state, the area under vegetable cultivation has been on a rise from 38.7 thousand ha (1991-92) to 88.37 thousand ha (2018-19). However, production has increased at a slow pace from 476.0 thousand metric tons (1991-92) to 1805.38 thousand metric tons (2018-19), despite use of high yielding input responsive varieties and improved agro-technologies (Anonymous, 2019). In Himachal Pradesh pea is cultivated on an area of 23.65 thousand ha producing 277.20 thousand metric tons (Anonymous, 2017a) and the area under pea is on an increase due to its premium returns fetches by the farmers under present agro-climatic conditions.

The total area under vegetable crops in Mandi district is about 11.109 thousand ha, which is approximately 20 per cent of the total area of Himachal Pradesh (Anonymous, 2017b). The agro-climatic conditions in the district are suitable for cultivation of varieties of off-season vegetables. Major cash crops grown in the district are pea, tomato, cabbage and cauliflower etc. The green pea from hills is available from April to November and this is the period for their freshness, flavour and sweetness.

Nutrient management is one of the largest shares of cost with its impact on potential yield and crop quality. Judicious use of nutrients envisages saving on natural resources for future use and protecting soil, water and air from pollution. Modern nutrient management strategy has shifted its focus towards the concept of practical sustainability with the components of eco-friendly approach to growers and to the crops.

Nutrition status of soil and leaves should be assessed to prepare a precise fertilizer application programme which can be ascertained only after knowing the sufficient and deficient levels of nutrients in relation to plant needs. Leaf and soil analysis should be undertaken, because soil and leaf test values are complimentary to one another and simultaneously the antagonism between elements should be kept in mind (Ozbek, 1977). The fertility status of soil is of prime importance for the optimum use of land to increase crop production. Thus, knowing fertility status of pea growing areas is very important for maximizing production and quality improvement, so it is very important to determine the fertility status of the soil for the optimum use of land to increase profitability. Since, fertility status of major pea growing areas of the district has not been documented so far therefore, the present investigation entitled "Nutritional status of vegetable growing areas of Mandi district of Himachal Pradesh" was undertaken with following objectives;

- To determine the available macro and micro nutrient status of soils of vegetable growing areas of Mandi district.
- To work out the relationship among available nutrients and leaf nutrient content of vegetable plants.

REVIEW OF LITERATURE

Chapter – 2

REVIEW OF LITERATURE

The demand for land, water and food has increased manifolds with population explosion. In its efforts to meet the basic needs, human kind is degrading these natural resources through unscientific exploitation and causing environmental problems. A soil resource inventory provides an insight into the potentialities and limitations of soils for its effective exploitation.

Poor soil fertility and inappropriate nutrient management strategies are the important major constraints contributing to food insecurity, malnutrition and ecosystem degradation. Thus, any soil fertility evaluation research must provide highly valuable information that can be used to eliminate these above-mentioned constraints, and thus can lead to sustained food security and well being of human society without harming the environment. The fact that at least 60 per cent of cultivated soils have plant growth limiting problems associated with nutrient deficiencies, makes soil fertility evaluation research a major promising area for meeting the global demand for sufficient food production and nutritional security. Hence, the present study entitled "**Nutritional status of vegetable growing areas of Mandi district of Himachal Pradesh"** is reviewed under the following heads:

2.1 Soil fertility status

2.1.1.1 Physical and chemical properties of soil

2.1.1.2 Macronutrients

2.1.1.3 Micronutrients

2.2 Macronutrients and micronutrients concentration in plants

2.3 Relationship of soil properties with nutrient concentration in soils

2.4 Relationship of soil nutrient contents with plant nutrients

2.1 Soil fertility status

Soil fertility effects productivity of soils considerably. It is affected by the natural (climate, biosphere, parent material, topography and time) and artificial factors *viz*., management practices (manuring, fertilization, crop rotations etc.). The primary purpose of evaluation of soil fertility is to provide basis for location specific fertilizer recommendations for high yields with improved quality. Parker *et al*. (1951) advocated the use of Nutrient Index concept for comparing the levels of soil fertility between the soil series. Therefore, an effort has been made to review the fertility status of soils of Himachal Pradesh vis-à-vis India and World.

2.1.1 Physical and chemical properties of soil

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

2.1.1.1 Soil texture

Soil texture is important for assessing nutrient supplying and retention power of soils as well as its potential to supply water and air to the plants. Water infiltration is more rapid in very coarse textured soils and plants suffer due to lack of an appropriate water holding capacity in such soils, while clay soils are good in water holding capacity. The texture also determines the magnitude of surface on which the reactions can occur.

Gupta *et al*. (1981) reported that in soils of Solan district, the average clay content was 32 per cent. They also reported the presence of illite, chlorite, degraded illite, montmorillonite and kaolinite in soils of Solan district of Himachal Pradesh. The higher clay content in the sub-surface layer may be ascribed to the downward translocation of clay under higher rainfall conditions and due to development of textural B horizons (Gupta and Verma, 1992).

Mahajan *et al.* (2007) revealed that silty loam was dominant texture of the soils irrespective of soil depth in Balh valley of Mandi district of Himachal Pradesh. According to Sharma and Kanwar (2010) the soil texture varied from sandy loam to sandy clay loam in pea growing soils of high dry temperate zone of Himachal Pradesh.

Chander *et al.* (2014) reported that soil texture in vegetable growing soils of sub-humid and wet-temperate zones of Himachal Pradesh were sandy loam to clay loam. Jamio (2014) revealed that soil texture in Kullu district were sandy loam to sandy clay loam.

Mondal *et al.* (2015) found that the textural classes of most of the soil samples varied from sandy clay loam to clay loam in vegetable growing area of Jammu district of Jammu-Kashmir. Kumari *et al.* (2017) revealed that sand, silt and clay content in cultivated 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.

Sharma *et al.* (2018a) studied the texture of soils of Kangra district of Himachal Pradesh and found to be varied from sandy loam to sandy clay loam irrespective of soil depth. Sharma *et al.* (2018b) observed that the soils of Kinnaur region of Himachal Pradesh varied from sandy loam to sandy clay loam in texture. Vista *et al.* (2019) showed that majority of the soils of vegetable super zone, Kaski, Nepal was silty loam in texture.

2.1.1.2 Bulk density (BD)

Soil bulk density is a dynamic property that varies with the soil structural conditions. In general, it increases with profile depth due to changes in organic matter content, porosity and compaction. Bulk density is a useful indicator for the assessment of soil health with respect to soil functions such as aeration and infiltration (Pattison *et al.* 2008; Reynolds *et al.* 2009).

According to Kumar and Verma (2005) bulk density decreases with increase in depth and value varied from 0.99 to 1.62 mg m^{-3} in soils of Palam valley of Himachal Pradesh. Mahajan *et al.* (2007) reported that bulk density of surface soils of vegetable growing (0.95 to 0.96 mg m^{-3}) areas was lower than those of maize (1.14 to 1.15 mg m^{-3}) and paddy (1.20 to 2.46 mg m^{-3}) growing soils of Balh valley in Mandi district.

Kyandiah (2012) also reported that bulk density varied from 1.25 to 1.55 and 1.29 to 1.57 g/cm^3 in 0-15 and 15-30 cm soil depth, respectively in soils of Solan district of Himachal Pradesh. Chaudhari *et al.* (2013) investigated the dependence of bulk density on texture, organic matter content and available nutrients (macro and micro nutrients) for soil of Coimbatore. Besides texture and organic matter content, nutrient concentration was also the most effective factor that affected the bulk density of soils. Bulk density ranged from 1.25 to 1.57 mg m^{-3}. A significant and negative correlation of BD with primary nutrients was also observed.

According to Kumar and Paliyal (2016) soil bulk density under different land uses of cold arid soils of Spiti valley of Himachal Pradesh varied from 1.17 to 1.50 mg m^{-3}, it decreased with increase in soil depth in all profile of soil under study.

Chandel *et al.* (2017) reported that mean bulk density under polyhouse condition (1.18 mg m^{-3}) was significantly lower than the open condition (1.25 mg m^{-3}) of district Mandi, Solan and Sirmour of Himachal Pradesh. According to Kumar *et al.* (2017b) found that bulk density in the surface soils under annual crops, apple plantation and pasture lands of Spiti valley of

Himachal Pradesh varied from 1.20 to 1.37, 1.25 to 1.28 and 1.23 to 1.38 mg m^{-3}, whereas, in the sub-surface soils, it varied from 1.20 to 1.55, 1.23 to 1.28 and 1.17 to 1.26 mg m^{-3}, respectively.

Kumar and Paliyal (2018) noticed that under mid hill humid conditions of North-West Himalayas bulk density in the surface soils under vegetable, paddy and maize growing areas from Ladhbadhol valley of Mandi district of Himachal Pradesh varied from 1.07 to 1.30, 1.09 to 1.32 and 1.09 to 1.29 mg m^{-3}, respectively. Whereas, in the sub-surface layer, BD varied from 1.0 to 1.28, 1.07 to 1.29 and 1.1 to 1.34 mg m^{-3}, respectively. Hosea *et al.* (2018) revealed that bulk density increased with soil depth between 10 and 100 cm given the good porosity for soil water movement and cation exchange capacity to hold the nutrients necessary for microbial activity in tropical forest ecosystem under monsoon climate in Malaysia.

2.1.1.3 Soil pH

Soil reaction (usually expressed as pH value) is the degree of soil acidity or alkalinity, which is caused by particular chemical, mineralogical and/or biological environment. Soil reaction affects nutrient availability and toxicity, microbial activity and root growth. Thus, it is one of the most important chemical characteristics of the soil solution because both higher plants and microorganisms respond so markedly to their chemical environment.

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

Shekhar (2009) while studying soils of North-Western Himalayas found that soil pH under forest, grassland and cultivated areas varied from 4.6 to 5.9, 5.3 to 5.7 and 4.9 to 5.9 for surface and 4.5 to 6.1, 5.4 to 5.8 and 4.2 to 6.0 for sub-surface layers, respectively. Thus, majority of soils were acidic to slightly acidic in reaction.

Sharma and Kanwar (2010) reported that in pea growing soils of dry temperate zones of Himachal Pradesh, pH ranged from 6.2 to 10.3 with mean value of 7.6. Vijayakumar *et al.* (2011) revealed that the soil pH ranged from 6.7 to 7.9 (neutral to alkaline in reaction) in Sirkali taluk of Tamil Nadu.

Chander *et al.* (2014) observed that the vegetable growing soils in wet temperate zone of Himachal Pradesh were more acidic (pH 5.2 to 6.8) in comparison to soils in mid-hills sub-humid zone (pH 5.8 to 7.5).

Mondal *et al.* (2015) reported that the soil pH ranged from 5.9 to 8.7 in vegetable growing soils of Jammu district. Rajput (2016) revealed that soil pH of four districts viz. Shimla, Sirmour, Solan and Bilaspur varied from 5.4 to 7.7 and classified the soils as slightly acidic to nearly neutral.

Kumari *et al.* (2017) reported that soil pH of cultivated soils of Himachal Pradesh varied from 5.4 to 7.4, respectively. Annepu *et al.* (2017) revealed that the pH of surface soils ranged from 6.5 to 7.8 in mid Himalayan region, Himachal Pradesh. Khadka *et al.* (2017) studied that the pH of soil samples varied from 4.4 to 7.5 in Regional Research Station, Tarahara, Sunsari, Nepal.

Mogta and Sharma (2018) revealed that the pH of the soils ranged from 5.3 to 7.4 in protected cultivation in some vegetable growing areas of Himachal Pradesh. Sharma *et al.* (2018b) reported that the pH of surface soils ranged from 5.5 to 7.5 with a mean value of 6.7 in Kinnaur region of Himachal Pradesh. Vista *et al.* (2019) revealed that soil pH of Pokhara, Lekhnath, Mahanagarpalika were found to be mostly neutral and value ranged from 4.7 to 7.8 in vegetable super zone, Kaski, Nepal.

2.1.1.4 Electrical conductivity (EC)

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

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

Vijayakumar *et al.* (2011) revealed that the electrical conductivity of the soil varied from 0.07 to 0.62 dS m^{-1} in Sirkali taluk of Tamil Nadu. Singh and Kumar (2012) reported that electrical conductivity ranged from 0.4 to 0.9 dS m^{-1} in vegetable growing area of Varanasi (Uttar Pradesh).

Kumar *et al.* (2017b) reported that the values of EC ranged from 0.19 to 0.50, 0.23 to 0.44 and 0.17 to 0.44 dS m^{-1} in surface and 0.18 to 0.74, 0.23 to 0.44 and 0.34 to 0.45 dS m^{-1} in sub-surface soil under annual crop, apple plantation and pasture lands of Spiti valley of Himachal Pradesh.

Mogta and Sharma (2018) reported that the electrical conductivity was found to be in a normal range (0.17 to 3.32 dS m^{-1}) in protective cultivation in some vegetable growing areas of Himachal Pradesh. Rai *et al.* (2018) reported that the electrical conductivity of soils varied from 0.05 to 0.35 dS m^{-1} in district Kishtwar of Jammu-Kashmir.

Kumar and Paliyal (2018) noticed that under mid hill humid conditions of North-West Himalayas EC values for the surface soils of vegetable, paddy and maize growing areas from Ladhbadhol valley of Mandi district of Himachal Pradesh varied from 0.14 to 0.49 dS m^{-1}, 0.22 to 0.45 dS m^{-1} and 0.25 to 0.44 dS m^{-1} in sub-surface layer its value ranged from 0.12 to 0.44, 0.22 to 0.44 and 0.22 to 0.43 dS m^{-1}, respectively.

Sharma and Sood (2019) recorded that the soils in Kinnaur region of Himachal Pradesh were low in soluble salt concentration with values ranging from 0.11 to 0.8 dS m^{-1}. Singh *et al.* (2019) revealed that the electrical conductivity (EC) of soils of Kanti block in Muzaffarpur district of Bihar varied from 0.15 to 0.92 dS m^{-1}. Patel *et al.* (2019) depicted that the electrical conductivity varied from 0.03 to 1.31 dS m^{-1} of the Sabarkantha district of Gujarat.

2.1.1.5 Organic carbon (OC)

Organic carbon content was revealed to vary from 0.3 to 8.33 per cent in the soils of different regions of Himachal Pradesh (Kaistha *et al.* 1990). Moderately high amount of organic carbon (1.40 to 2.58%) was recorded in the mid-altitude soils of outer Himalayas (Singh *et al.* 1991). Tripathi *et al.,* (1992) reported that organic carbon content in the soils of Mandi district ranges from 0.20 to 2.6%.

Mahajan *et al.* (2007) revealed that organic carbon ranged from 0.62 to 1.10 per cent in soils of vegetable growing areas of Balh valley of Himachal Pradesh. Najar *et al.* (2009) found the organic carbon content in north facing pedons to vary from 0.16 to 3.5 per cent, whereas, in southern aspect it ranged from 0.1 to 2.4 per cent in soils of Kashmir valley.

Devi and Kumar (2010) found that the organic carbon content in the surface layer soils of Karnataka ranged from 1.47 to 5.29 per cent and it decreased with depth. The OC content ranged from 4.2 to 80.8 g kg^{-1} in pea growing soils of dry temperate zone of Himachal Pradesh (Sharma and Kanwar, 2012). Chander *et al.* (2014) revealed that the organic carbon in vegetable growing soils of sub-humid and wet-temperate zones was medium to high (9.3 to 27.5 and 9.5 to 22.7 g kg^{-1}).

Kumar and Paliyal (2016) found that organic carbon of cold arid soils under different land uses of Spiti valley, Himachal Pradesh were ranged between 7.6 to 27.4 g kg^{-1}. Loria *et al.* (2016) revealed that in Shiwalik hills of Himachal Pradesh the soils under dominant cropping systems were having mean organic carbon varied from 7.34 to 9.70 g kg^{-1} and 5.41 to 7.41 g kg^{-1} in surface and sub-surface soils.

Amara *et al.* (2017) observed that the organic carbon content of the soils of Bogur micro-watershed in Karnataka ranged from 0.09 to 5.15 per cent. Khadka *et al.* (2017) reported that the organic matter content ranged from 0.78 to 4.42 per cent in Regional Research Station, Sunsari, Nepal. Annepu *et al.* (2017) reported that the organic carbon of surface soils ranged from 0.15 to 1.98 per cent in Solan district of Himachal Pradesh.

Sharma *et al.* (2018a) observed that the organic carbon content ranged from 7.65 to 17.85 g kg^{-1} in surface and 6.75 to 16.65 g kg^{-1} in sub-surface soils of Kangra district of Himachal Pradesh. Rai *et al.* (2018) reported that the organic carbon content of soils ranged from 5.1 to 8.5 kg^{-1} in district Kishtwar of Jammu and Kashmir. Sharma and Sood (2019) observed that organic carbon of Kinnaur district soils ranged from 8.4 to 55 g kg^{-1}.

2.1.2 Macronutrients

2.1.2.1Available nitrogen (N)

Nitrogen is the fourth plant nutrient taken up by plants in greatest quantity next to carbon, oxygen and hydrogen, but it is one of the most deficient elements for crop production (Sanchez, 1976; Mengel and Kirkby, 1987; Mesfin, 1998). The total N content of a soil is directly associated with its organic carbon content and its amount on cultivated soils is between 0.03 to 0.04 per cent by weight (Mengel and Kirkby, 1987; Tisdale *et al.*, 1995). Ramamoorthy and Bajaj (1969) reported that the soils of India were low in available N. Raina (1988) studied the citrus growing soils of Poanta valley of Himachal Pradesh and reported the soils to be low in available N.

Kumar and Verma (2005) studied the fertility status of soils of Palam valley of Himachal Pradesh and reported that the available N ranged from 188.1 to 392.0 kg ha^{-1} and 86.3 to 252.5

kg ha^{-1} in surface and sub-surface soils. Laxminarayan (2006) reported that available nitrogen content varied from 213 to 452 kg ha^{-1} in the soils of Mizoram.

Mahajan *et al.* (2007) revealed that available N ranged from 268.2 to 494.2 kg ha^{-1} in soils of vegetable growing areas of Balh valley of Himachal Pradesh. In soils of Jalna district of Maharashtra, Dhale and Prasad (2009) found that available nitrogen content varied from 68 to 33 kg ha^{-1}. The available nitrogen content in soils of Andhra Pradesh varied from 133 to 188 kg ha^{-1} and the content decreased with depth (Rajeshwar *et al.*, 2009).

Singh and Kumar (2012) revealed that available N content varied from 160 to 685 kg ha^{-1} in vegetable growing area of Varanasi region (UP). Chander *et al.* (2014) found that the available N content in vegetable growing soils of sub-humid and wet-temperate zones of Himachal Pradesh was medium (282 to 439 and 282 to 502 kg ha^{-1}).

Ramana *et al.* (2015) revealed that available N content of Sri Ganganagar district of Rajasthan soils ranged between 100.35 to 326.14 kg ha^{-1}. Loria *et al.* (2016) reported that in Shiwalik hills of Himachal Pradesh the soils under dominant cropping systems having surface and sub-surface soils mean values of available N ranged from 157.36 to 267.21 and 113.55 to 202.15 kg ha^{-1}. Singh *et al.* (2017) reported that the available N content in the surface soil and sub-surface soil ranged between 287 to 349 and 216 to 278 kg ha^{-1} in Mirzapur district of Uttar Pradesh.

Mogta and Sharma (2018) reported that the available nitrogen content in the surface soils of the polyhouses in the four districts (Shimla, Solan, Sirmaur and Bilaspur) ranged from 112.80 to 570.70 kg ha^{-1}. Sharma *et al.* (2018b) revealed that available nitrogen ranged from 250 to 672 kg ha^{-1} with a mean value of 508.7 kg ha^{-1} in soils of Kinnaur region of Himachal Pradesh. Singh *et al.* (2019) showed that the available nitrogen content of soil samples of district Muzaffarpur, Bihar ranged from 111.99 to 137.50 kg ha^{-1}.

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

2.1.2.2 Available phosphorus (P)

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

Chand *et al.* (2006) reported that available phosphorus content varied from 5.8 to 63.9 kg ha^{-1} in soils of Punjab. According to Sharma and Kanwar (2012) the available P in pea growing soils of dry temperate zone of Himachal Pradesh varied from 2 to 89 kg ha^{-1} with a mean value of 25 kg ha^{-1}.

Doneriya *et al.* (2013) noticed that the available P content of *Alfisol* ranged from 8.91 to 24.51 kg ha^{-1} in soils of district Mirzapur, Uttar Pradesh. Loria *et al.* (2016) reported that that the mean available P in surface and sub-surface soils varied from 9.8 to 19.9 and 7.0 to 14.1 kg ha^{-1} in dominant cropping systems of Shiwalik hills of Himachal Pradesh.

Chandel *et al.* (2017) revealed that the mean available phosphorus ranged from 82.9 and 55.4 kg ha^{-1} in polyhouse and open conditions of district Mandi, Solan and Sirmour of Himachal Pradesh. Singh *et al.* (2017) reported that the available P content in the surface and sub-surface soils ranged between 17.3 to 19.3 and 19.6 to 21.2 kg ha^{-1} in Mirzapur district of Utttar Pradesh, respectively.

Kumar and Paliyal (2018) observed that available P content ranged from 10.8 to 22.1, 16.9 to 24.1 and 16.4 to 25.3 kg ha^{-1} for surface soils of vegetable, paddy and maize growing areas from Ladhbadhol valley of Himachal Pradesh. In sub-surface soils the corresponding values were 10.5 to 22.0, 15.1 to 23.1 and 15.3 to 24.0 kg ha^{-1}. Khadka *et al.* (2018) revealed that the available phosphorus ranged from 10.7 to 157.9 mg kg^{-1} in Chungbang farm situated in Nepal.

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

2.1.2.3 Available potassium (K)

Ramamoorthy and Bajaj (1969) reported that the soils of India were medium in available K. Thakur *et al*. (1971) found that the cultivated soils of Seeraj and Karsog blocks in Mandi district of Himachal Pradesh were low in available K. Verma *et al.* (1985) characterized the soils of Kangra, Kullu, Mandi and Sirmour areas of Himachal Pradesh and found the contents of available K ranging from 4.26 to 1507 kg ha^{-1}.

Kumar and Verma (2005) studied the fertility status of soils of Palam valley of Himachal Pradesh and reported that the available K varied from 89.8 to 561.2 kg ha^{-1} and 162.4 to 314.6 kg ha^{-1} in surface and sub-surface horizons. Mahajan *et al.* (2007) revealed that available K ranged from 129.2 to 294.6 kg ha^{-1} in soils of vegetable growing areas of Balh valley in Mandi district. Vara Prasad Rao *et al.* (2008) characterized the soils of Andhra Pradesh as medium to high in available K and ranged from 135 to 320 kg ha^{-1}.

Dhale and Prasad (2009) while characterizing and classifying the soils of district Jalna, Maharashtra found that available potassium content of soils ranged from 195 to 1287 kg ha^{-1}. Vijayakumar *et al.* (2011) reported that available K ranged from 135.85 to 432.25 kg ha^{-1} in Sirkali taluk of Tamil Nadu.

According to Sharma and Kanwar (2012) the available K content in pea growing soils of dry temperate zone of Himachal Pradesh varied from 120 to 1497 kg ha^{-1}. Chander *et al.* (2014) reported that the available K in vegetable growing soils of sub-humid and wet-temperate zones was medium to high (39 to 560 and 67 to 504 kg ha^{-1}, respectively). Kumar and Paliyal (2016) revealed that available potassium varied from 132 to 281 kg ha^{-1} under different land uses of cold arid soils of Spiti valley of Himachal Pradesh.

Kumar *et al.* (2017a) reported that the available K content ranged from 85.0 to 953.0 kg ha^{-1} in all five talukas of Koriya district of Chhattisgarh. Kumar *et al.* (2017b) found that available phosphorus content ranged from 4 to 82, 20 to 53 and 13 to 80 kg ha^{-1} for the surface soils under annual crops, apple plantation and pasture lands of Spiti valley of Himachal Pradesh, respectively. In sub-surface soils the corresponding values were 8 to 89, 20 to 53 and 17 to 31 kg ha^{-1} under respective land uses. Annepu *et al.* (2017) reported that the available potassium of surface soils varied from 70.56 to 448.0 kg ha^{-1} in Solan district of Himachal Pradesh.

Sharma *et al.* (2018a) revealed that available K content in surface and sub-surface soils varied from 292.32 to 749.28 and 271.04 to 715.68 kg ha^{-1} under district Kangra, Himachal Pradesh. Singh *et al.* (2019) reported that the available K values varied from 137.2 to 244.7 kg ha^{-1} in Kanti block of Muzaffarpur district of Bihar. Vista *et al.* (2019) showed that the amount of available potassium in the soils of Pokhara, Lekhnath, Mahanagarpalika vegetable super zone, Kaski, Nepal ranges from 0 to 1980 kg ha^{-1}.

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

2.1.2.4 Exchangeable calcium (Ca)

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

Mahajan *et al.* (2007) revealed that exchangeable Ca varied between 2.07 to 5.12 [cmol (p^+) kg^{-1}] in soils of vegetable growing areas of Balh valley of Himachal Pradesh. Dhale and Prasad (2009) characterized and classified soils of district Jalna, Maharashtra and found the exchangeable Ca content varied from 24.48 to 55.61 [cmol (p^+) kg^{-1}].

Chander *et al.* (2014) revealed that the exchangeable Ca in vegetable growing soils of high hills wet-temperate zones [761 to 1611 cmol (p^+) kg^{-1}] was lower in comparison to mid hills sub-humid zone [276 to 2195 cmol (p^+) kg^{-1}] of Himachal Pradesh. Ramana *et al.* (2015) reported that the exchangeable Ca content of district Sri Ganganagar, Rajasthan soils ranged from 0.4 to 10.2 cmol (p^+) kg^{-1}.

According to Chandel *et al.* (2017) the mean exchangeable Ca was found more under polyhouse conditions [11.43 cmol (p^+) kg^{-1}] than open conditions [10.31 cmol (p^+) kg^{-1}] in different districts of Himachal Pradesh.

Sharma *et al.* (2018a) reported that exchangeable Ca content in surface and sub-surface soils varied from 3.07 to 5.91 and 3.01 to 5.62 [cmol (p^+) kg^{-1}] in mango growing area of Kangra district of Himachal Pradesh.

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

2.1.2.5 Exchangeable magnesium (Mg)

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

Exchangeable magnesium content varied from 0.1 to 4.2 [cmol (p^+) kg^{-1}] in the soils of Central Himalayas of Himachal Pradesh representing sub-humid temperate highlands (Kaistha and Gupta, 1993), 0.7 to 10.5 [cmol (p^+) kg^{-1}] in the soils of North-Western Himalayas (Gupta and Tripathi, 1996).

Mahajan *et al.* (2007) reported that exchangeable Mg ranged from 1.28 to 2.90 cmol (p^+) kg^{-1} in soils of vegetable growing areas of Balh valley of Himachal Pradesh. Shekhar (2009) observed that exchangeable magnesium content in surface soils of forest, grassland and cultivated lands of high rainfall areas in Kangra, Chamba and Mandi districts of Himachal Pradesh varied from 0.63 to 1.03, 0.36 to 0.75 and 0.75 to 0.88 cmol (p^+) kg^{-1}, and respective values in sub surface soils were 0.40 to 0.93, 0.20 to 0.65 and 0.59 to 0.79 cmol (p^+) kg^{-1}.

Singh and Kumar (2012) reported that exchangeable Mg varied from 0.8 to 1.10 cmol (p^+) kg^{-1} in vegetable growing area of Varanasi (UP). Ramana *et al.* (2015) reported that the exchangeable magnesium content in soils of Raisingh Nagar block of district Sri Ganganagar from 0.5 to 8.6 cmol (p^+) kg^{-1}. Kumar and Paliyal (2016) revealed that exchangeable Mg varied from 2.4 to 3.7 cmol (p^+) kg^{-1} under different land uses of cold arid soils of Spiti valley of Himachal Pradesh.

Amara *et al.* (2017) revealed that the magnesium content of Bogur micro-watershed soils in Karnataka varied from 1.9 to 23.2 meq/100g. Kumar *et al.* (2017b) revealed that exchangeable Mg content in surface soils of annual crops, apple plantation and pasture lands of Spiti valley of Himachal Pradesh varied from 1.16 to 3.77, 1.94 to 3.38 and 1.24 to 2.95 cmol (p^+) kg^{-1} and the corresponding values in sub-surface soils ranged from1.27 to 3.34, 1.94 to 3.38 and 1.34 to 3.31 cmol (p^+) kg^{-1}.

Sharma *et al.* (2018a) revealed that exchangeable Mg content in surface and sub-surface soils varied from 2.02 to 3.30 and 1.34 to 2.90 [cmol (p^+) kg^{-1}] in citrus growing soils of Kangra district of Himachal Pradesh. Khadka *et al.* (2018) revealed that the magnesium content ranged from 13.20 to 150 mg kg^{-1} of soil of Chungbang farm in Nepal.

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

2.1.2.6 Available sulphur (S)

Tripathi and Singh (1992) reported that soluble sulphate sulphur content ranged from 5.5 to 21.2 mg kg^{-1} and shows a decreasing trend with the depth. Low content of this form was recorded in sub-surface horizons. Pandey *et al.* (2000) revealed the wide variability in the availability of S was observed in different soil associations of district Kanpur in Uttar Pradesh. The available S contents varied from 5.8 to 53.8 mg kg^{-1}. In correlation studies S availability was found significantly and positively affected by organic matter, CEC and finer soil particles. Sharma *et al.* (2001) reported that majority of soils of Himachal Pradesh were deficient in sulphur.

Kour and Jalali (2008) reported that available sulphur varied from 8 to 51mg kg^{-1} in soils of Jammu region (J and K). Patel *et al.* (2011) revealed that the available sulphur ranged from 2 to 49 mg kg^{-1} in soils of Gujarat.

Singh *et al.* (2013) observed that available sulphur varied from 12 to 47 mg kg^{-1} in soils of North India. Narale *et al.* (2015) found that available sulphur content ranged from 1 to 58 mg kg^{-1} in soils of Maharashtra. Kumar and Paliyal (2016) revealed that available sulphur varied from 11 to 81 kg ha^{-1} under different land uses of cold arid soils of Spiti valley of Himachal Pradesh. Amara *et al.* (2017) found that the sulphur content of the soils of Bogur micro-watershed in Karnataka varied from low to high (0.6 to 35.6 ppm).

Sharma *et al.* (2018a) reported that available S content in surface and sub-surface soils varied from 12.6 to 19.7 and 9.8 to 15.8 kg ha^{-1} in orchards soils of Kangra district of Himachal Pradesh. Kashiwar *et al.* (2018) showed that the available sulphur content in soils was ranging from 6.7 to 10.25 kg ha^{-1} in Agricultural Farm of Rajiv Gandhi South Campus of Banaras Hindu University in Uttar Pradesh.

2.1.3 Micronutrients

2.1.3.1 DTPA-extractable iron (Fe)

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

Mahajan *et al.* (2007) revealed that DTPA-extractable Fe ranged from 28.2 to 99.3 ppm in soils of vegetable growing areas of Balh valley of Himachal Pradesh. Rattan *et al.* (2008) found that the contents of Fe in Indian soils varied from 3.4 to 68.1 mg kg^{-1}.

Vijayakumar *et al.* (2011) revealed that the content of DTPA-Fe contents in soils varied from 2.94 to 6.75 mg kg^{-1} in Sirkali taluk of Tamil Nadu. Doneriya *et al.* (2013) revealed that available iron content in *Alfisol* varied from 12.2 to 90.4 mg kg^{-1} in soils of Mirzapur district, Uttar Pradesh. Chander *et al.* (2014) reported that DTPA-extractable Fe ranged between 10.6 to 70.8 and 22.8 to 96.6 mg kg^{-1} in vegetable growing soils of mid-hills sub-humid and high hill wet-temperate zones of Himachal Pradesh.

Mondal *et al.* (2015) observed that available iron content ranged from 1.29 to 10.30 mg kg^{-1} in vegetable growing area of district Jammu. Sandhu *et al.* (2016) reported that DTPA-extractable Fe in the different salt-affected soils ranged between 1.08 to 31.2 mg kg^{-1} in Muktsar district of Punjab.

Rai *et al.* (2018) reported that the soil DTPA-extractable Fe ranged from 9.45 to 23.54 mg kg^{-1} in Kishtwar district of Jammu and Kashmir. Kakar *et al.* (2018b) found that DTPA-extractable Fe content ranged from 7.03 to 36.46 mg kg^{-1} in soils of Saproon valley of Himachal Pradesh. Singh *et al.* (2019) reported that the available Fe content varied from 9.42 to 31.78 ppm in Muzaffarpur district of Bihar.

The literature clearly indicates a significant variation in available Fe content under different locations. In general, Indian soils were found to have sufficient and higher available Fe contents at different locations. Available Fe content also show decreasing trend with increasing soil depth.

2.1.3.2 DTPA-extractable manganese (Mn)

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

Tripathi *et al.* (1994) reported that average available Mn content in the soils of Himachal Pradesh was 29.0 mg kg^{-1}. Significant Correlation of DTPA- Mn was found with organic carbon (r=0.28*).

Nazif *et al.* (2006) have reported DTPA-extractable Mn vary from 4.59 to 21.08 mg kg^{-1} at different locations in Jammu and Kashmir soils. DTPA-extractable Mn values varied from 5.0 to 23.9 mg kg^{-1} in the soils under different land uses in Chambal ravines (Somasundaram *et al.* 2009).

Doneriya *et al.* (2013) observed that available Mn in the soils of Marihan block of Mirzpur district (UP) ranged from 6.4 to 50.1 mg kg^{-1}.

Mahla *et al.* (2014) reported that the DTPA-extractable Mn content of soil under study (red and yellow soil) varied from 0.3 to 64.8 mg kg^{-1} with a mean value of 31.57 mg kg^{-1} of Navagarh block in Janjgir-Champa district of Chattisgarh.

Amara *et al.* (2017) revealed that the manganese content of soils of Bogur micro-watershed in Karnataka varied from 0.2 to 40.3 ppm. Khadka *et al.* (2018) revealed that the available manganese content varied from 1.10 to 58.86 mg kg^{-1} of soil of Chungbang farm in Nepal. Kakar *et al.* (2018b) found that DTPA-extractable Mn content ranged from 0.3 to 29.0 mg kg^{-1} in soils of Saproon valley of Himachal Pradesh. Patel *et al.* (2019) observed that the DTPA-extractable Mn content in soils of Sabarkantha district of Gujarat ranged from 2.31 to 29.31 mg kg^{-1}.

The literature described above indicates that DTPA-extractable Mn status of the soil was found to be in deficient to sufficient range and it decreased with soil depth.

2.1.3.3 DTPA-extractable copper (Cu)

DTPA-extractable Cu varied from 1.28 to 4.88 mg kg^{-1} in Saproon valley of Solan district (Thakur and Bhandari, 1986). In the soils of Kashmir, available Cu content in high altitude soils ranged from 0.07 to 0.33 mg kg^{-1}. DTPA-extractable Cu was found to be high in surface horizons and decreased with the increasing depth of profile (Jalali *et al*., 1989). The low altitude soils of Sikkim were high in available Cu than the one at high altitude (Lahiri and Chakravarti, 1989). Tripathi *et al.* (1994) reported that the content of DTPA-Cu ranged from 0.4 mg kg^{-1} to 4.8 mg kg^{-1}, with an average value of 1.7 mg kg^{-1} in the soils of Himachal Pradesh.

Mahajan *et al.* (2007) revealed that DTPA-extractable Cu ranged from 1.87 to 2.76 ppm in soils of vegetable growing areas of Balh Valley of Himachal Pradesh. Talukdar *et al.* (2009) reported that under different land uses DTPA-extractable Cu ranged from 0.35 to 6.05 mg kg^{-1} with a mean value of 3.83 mg kg^{-1} in rice growing soils of Golaghat district in Assam. A study was undertaken by Sharma and Kanwar (2010) in pea growing soils of high hill dry temperate zone of Himachal Pradesh and revealed that the DTPA-extractable Cu was ranged from 0.02 to 4.10 mg kg^{-1} with a mean value varied from 0.8 mg kg^{-1}.

Mahla *et al.* (2014) found that in Navagarh block of Janjgir-Champa district of Chattisgarh, the DTPA-extractable copper content of soils under study varied from 0.16 to 10.84 mg kg^{-1} with mean value 2.13 mg kg^{-1}. Mondal *et al.* (2015) revealed that DTPA-extractable Cu ranged from 0.04 to 3.67 mg kg^{-1} in vegetable growing area of Jammu district.

Kakar *et al.* (2018b) found that DTPA-extractable Cu content ranged from 1.15 to 12.75 mg kg^{-1} in soils of Saproon valley of Himachal Pradesh.

2.1.3.4 DTPA-extractable zinc (Zn)

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

Sakal *et al*. (1986) reported that the DTPA-extractable Zn in calcareous soils ranged from 0.34 to 3.42 ppm. DTPA-extractable Zn contents were found to vary from 0.56 to 6.76 mg kg^{-1} in the temperate vegetable growing valley of Himachal Pradesh (Thakur and Bhandari, 1986). Further, Jalali *et al*. (1989) have reported the DTPA-extractable zinc to vary from 0.35 to 0.65 mg kg^{-1} in the high altitude soils of Kashmir. They further reported that benchmark soils of Kashmir were deficient (0.15 to 1.00 mg kg^{-1}) in DTPA-extractable zinc.

Singh and Kumar (2012) reported that available Zn varied from 0.08 to 0.76 mg kg^{-1} in vegetable growing area of Varanasi (Uttar Pradesh). Chander *et al.* (2014) reported that DTPA-extractable Zn ranged from 0.64 to 11.0 and 0.44 to 2.06 mg kg^{-1} in vegetable growing soils of mid-hills sub-humid and high hill wet-temperate zones of Himachal Pradesh.

Biswas *et al.* (2017) revealed that the DTPA-extractable Zn content varied from 2.70 to 3.19 mg kg^{-1} with highest content (3.19 mg kg^{-1}) in Sirmaur and lowest (2.70 mg kg^{-1}) in Solan district of Himachal Pradesh. Rai *et al.* (2018) revealed that the soil DTPA-extractable Zn ranged from 0.40 to 3.41mg kg^{-1} in Kishtwar district of Jammu and Kashmir. Kakar *et al.* (2018b) found that DTPA-extractable Zn content ranged from 0.01 to 4.23 mg kg^{-1} in soils of Saproon valley of Himachal Pradesh. Patel *et al.* (2019) indicated that DTPA-extractable Zn content in soils of Sabarkantha district of Gujarat ranged from 0.08 to 3.97 mg kg^{-1}.

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

2.2 Macro and micronutrients concentration in plants

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

2.2.1 Macronutrients

Thakur (1979) reported that the N, P and K content in the leaves of cauliflower in Saproon valley of Himachal Pradesh varied from 1.7 to 5.0, 0.14 to 0.4 and 1.22 to 3.20 per cent with the mean values of 3.71, 0.33 and 2.22 per cent, respectively. The range of Ca, Mg and S in the samples varied from 2.1 to 5.3, 0.26 to 0.78 and 0.17 to 0.45 per cent with the mean values of 3.27, 0.51 and 0.30 per cent, respectively.

Mahler *et al.* (1988) revealed that the N, P and K concentration of leaf tissue usually ranges between 1.8 to 3.4, 0.23 to 0.49 and 0.6 to 1.4 per cent for pea, lentil and chickpea. The sulphur content of leaf tissue usually ranges between 0.1 and 0.25 per cent and tissue calcium values varied between 0.8 and 2.2 per cent, while magnesium values were found between 0.1 and 0.3 per cent.

Hochmuth and Hanlon (1995) reported that the cauliflower in buttoning stage contains 3.0 to 5.0 per cent N, 0.4 to 0.7 per cent P, 2.0 to 4.0 per cent K, 0.8 to 2.0 per cent Ca, 0.25 to 0.60 per cent Mg, 0.6 to 1.0 per cent S. Whereas in case of bell pepper prior to blossoming stage N, P, K Ca, Mg and S contents were found to varied between 4.0 to 5.0, 0.3 to 0.5, 5.0 to 6.0, 0.9 to 1.5, 0.35 to 0.60 and 0.35 to 0.60 per cent, respectively.

Campbell (2000) revealed that sufficiency range of N, P, K, Ca, Mg and S in the tomato leaves of greenhouse ranged from 3.5 to 5.0, 0.30 to 0.65, 3.5 to 4.5, 1.0 to 3.0, 1.0 to 3.5 and 0.2 to 1.0 per cent, respectively.

Khajuria (2010) reported that concentration of macronutrient in the leaves of vegetable crops in the Baddi-Barotiwala-Nalagarh of Solan district ranged from 2.25 to 2.42, 0.36 to 0.39 and 0.60 to 0.79 per cent with respect to case of nitrogen, phosphorous and potassium contents, respectively.

Thakur *et al.* (2018) conducted a field experiment at Solan district of Himachal Pradesh and reported that the leaf N, P and K contents in cauliflower crop were 2.81, 0.46 and 1.74 per cent, respectively.

Mogta and Sharma (2018) reported that the leaf N, P and K contents in the capsicum grown under polyhouse conditions, varied from 2.80 to 6.44, 0.20 to 0.90 and 2.06 to 6.23 per cent, respectively. The majority of plant samples were found sufficient in N, P and K content.

Kakar *et al.* (2018a) observed that the amount of N, P, K, Ca, Mg and S content in the tomato leaves varied from 3.45 to 5.77, 0.28 to 0.89, 2.10 to 4.40, 0.85 to 4.45, 0.15 to 1.11 and 0.23 to 0.87 per cent, respectively.

Kumari and Tripathi (2018) conducted a field experiment at Solan district of Himachal Pradesh and revealed that leaf N, P and K content in pea crop were 4.05, 0.31 and 2.01per cent, respectively.

2.2.2 Micronutrients

Cannel *et al.* (1960) observed that the Cu content of tomato leaves under greenhouse condition, ranged from 3.1 to 12.3 ppm, which was neither deficient nor toxic to the plant. Thakur (1979) reported that Zn and Cu content in the leaves of cauliflower in Saproon valley of Himachal Pradesh varied from 8 to 45 and 2 to 20 ppm with mean values of 21.9 and 6.7 ppm, respectively.

Mahler *et al.* (1988) observed that leaf tissue Cu concentrations varied between 6 and 20 mg kg^{-1}. Plant leaf tissue should contain a minimum of 50 mg kg^{-1} Fe to sustain satisfactory growth. Manganese concentration in pea leaf tissue ranges between 20 and 350 m*g* kg^{-1}.

Hochmuth and Hanlon (1995) reported that the cauliflower at buttoning stage contains 3 to 60 ppm Fe, 30 to 80 ppm Mn, 30 to 50 ppm Zn and 5 to 10 ppm Cu. Whereas in case of bell pepper prior to blossoming stage Fe content was found to be 20 to 150 ppm, Mn 30 to 100 ppm, Zn 20 to 80 ppm and Cu 5 to 10 ppm.

Campbell (2000) reported that sufficiency range in the most recent mature leaves of greenhouse tomato was 50 to 300, 25 to 200, 18 to 80 and 5 to 35 ppm for Fe, Mn, Zn and Cu contents, respectively.

Khajuria (2010) reported that concentration of macronutrient in the leaves of vegetable crops in the Baddi-Barotiwala-Nalagarh of Solan district ranged from 8.10 to 10.04, 0.53 to 0.86, 8.84 to 9.25 and 0.74 to 1.59 ppm with respect to Mn, Cu, Fe and Zn content, respectively for different vegetable crops. The range of Cu in pea grown in high hilly dry temperate zone of Himachal Pradesh area varied from 1.0 to 56.0 mg kg^{-1} with a mean value of 12.0 mg kg^{-1} (Sharma and Kanwar, 2010).

Kakar *et al.* (2018a) revealed that tomato leaf Fe, Mn, Cu and Zn content ranged between 271.7 to 847.8, 21.0 to 476.7, 20.1 to 105.4 and 20.8 to 189.4 mg kg^{-1} in Saproon valley of Himachal Pradesh, respectively. Mogta and Sharma (2018) reported that the leaf Fe, Mn, Cu and Zn contents in the capsicum grown under polyhouse conditions, varied from 310.1 to 386.5 ppm, 137.5 to 218.8 ppm, 37.0 to 49.6 ppm and 42.5 to 53.3 ppm, respectively.

2.3 Relationship of Soil properties with nutrient content in soils

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

2.3.1 Soil pH

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

Katyal and Aggarwal (1982) depicted an inverse relationship of the soil pH with available micronutrient cations viz., Fe, Mn, Zn and Cu. Mishra *et al* (1990) observed a positive relationship of soil pH with available P, Cu and Mn in foot hill soils of Himalayas.

Sharma and Kanwar (2010) reported soil pH had significant and negative correlation with DTPA-Cu in pea growing soils of Spiti valley. Singh and Kumar (2012) found that soil pH was positively and significantly correlated with available primary and secondary nutrients. Soil pH exhibit a significant and negative relationship with micronutrients, thereby indicating that availability of Zn, Fe, Cu and Mn decreased with an increase in pH.

Chander *et al.* (2014) reported a negative and significant correlation between soil pH and Fe in sub-humid and wet temperate zone of Himachal Pradesh. Mahla *et al.* (2014) revealed a negative and significant correlation of soil pH with DTPA-Mn, Fe, Cu and Zn.

Mondal *et al.* (2015) depicted a significant and positive correlation of soil pH with available Zn of the soil. Soil pH was negatively and significantly correlated with available copper, manganese and iron. Ramana *et al.* (2015) revealed the soil pH (r = 0.288**) was highly positively correlated with available N. Available K showed non-significant relationship with pH (r = -0.37). Available sulphur in these soil indicated significant relationship with pH (r = 0.341*). Calcium depicted non-significant correlation with pH (r= 0.061).

Annepu *et al.* (2017) reported that available Zn in the soil has significant and negative relationship with pH (r = -0.484**) thereby indicating that availability of Zn increases at lower pH levels. Fe and Cu were negatively and significantly correlated with soil pH (r = - 300** and r = -0.345**) indicating their higher availability at acidic pH.

Kakar *et al.* (2018b) depicted a highly significant and negative correlation was observed between pH and DTPA-Fe (r = -0.66**). Kashiwar *et al.* (2018) reported that soil pH was positively correlated with EC, OC, N, P, K, S and Zn. Sharma *et al.* (2018a) reveals that the soil pH of the surface layer and sub-surface layer was significantly and positively correlated with available P (r = 0.38* and r= 0.36*) in soils of Kangra district of Himachal Pradesh.

Patel *et al.* (2019) reported a negative and significant correlation of soil pH with available Fe, Mn and Zn in soils of Sabarkantha district of Gujarat. Pandey *et al.* (2019) observed that available micronutrients in soils were highly significantly and negatively correlated with the soil pH with r = -0.858** for Zn, r = -0.920** for Fe, r = -0.871** for Cu and r = -0.923** for Mn. Soil pH was highly negatively correlated with available P (r = -0.878**).

2.3.2 Electrical conductivity (EC)

EC is a measure of soluble salt concentration in the soil solution. When a soil solution containing a relatively large amount of dissolved salts is brought into contact with a plant cell it causes shrinkage of the protoplasmic lining. This action, called plasmolysis increases with the concentration of the salt solution. Higher concentration of dissolved salts in any soil affects plant growth adversely.

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

Singh and Kumar (2012) found that EC was positively correlated with available primary and secondary nutrients. Micronutrients exhibit a significant negative relationship with EC, thereby indicating that availability of Zn, Fe, Cu and Mn decreased with an increase of soil EC. Mahla *et al.* (2014) found a negative and significant correlation of EC with Mn, Zn and Fe in soils of Chattisgarh.

Mondal *et al.* (2015) showed a negative and significant correlation of EC with available Mn and Zn. Ramana *et al.* (2015) revealed that EC has not a significant relationship with N. EC has negative and non-significant correlation with phosphorus. Available K showed non-significant relationship with EC and bulk density. Sulphur in soil showed negative non-significant relationship with EC. Calcium indicated negative and significant relationship with EC.

Sandhu *et al.* (2016) showed significant and positive correlation of EC with DTPA-Fe in soils of Mukhtar district of Punjab. Kashiwar *et al.* (2018) found that electrical conductivity was positively and significantly correlated with organic carbon, nitrogen, phosphorus, potassium, sulphur, zinc, iron and copper. Sharma *et al.* (2018a) reported that the electrical conductivity of the surface layer was found to be significantly and positively correlated with available P and Mg. For the sub-surface layer, a significant and positive correlation existed between EC and Mg.

2.3.3 Soil organic carbon

Bhandari and Randhawa (1985) observed a positive correlation of organic carbon with available micronutrient elements in soils of district Shimla.

Mahajan *et al.* (2007) showed a positive and significant correlation of organic carbon with available N, P, K, Ca, Mg, Zn, Cu and Mn in Balh valley of Himachal Pradesh. Sharma and Kanwar (2010) found that organic carbon was significantly and positively correlated with copper.

Singh and Kumar (2012) reported that a positive and significant correlation of organic carbon with available N, P and S.

Chaudhari *et al*. (2013) studied the relationships between some physical and chemical properties of soil such as $CaCO_3$, organic matter content (OMC), total macro and micro nutrient content with soil bulk density. The results revealed soil bulk density showed negative relationships with all soil properties ($CaCO_3$, OMC, total macro and total micro nutrient content).

Chander *et al.* (2014) depicted a positive correlation between C and all DTPA micronutrients suggesting their high availability and are controlled by soil component.

A significantly positive correlation of soil organic carbon with soil available nitrogen, phosphorus and potassium content was observed by Patil *et al.* (2015).

Mondal *et al.* (2015) indicated a negative and significant correlation (r = -0.306**) between DTPA-extractable Cu indicating that an organic carbon affected the availability of Cu in the soil. Manganese had negative correlation with soil organic carbon. DTPA-extractable Fe bears significant relationship with organic carbon (r = 0.363**). This indicates that soils rich in organic carbon are likely to have higher Fe content. Ramana *et al.* (2015) revealed that the OC was positively correlated with available N (r = 0.069*) and Available K (r= 0.307**).

Singh *et al.* (2017) revealed that the available K content in surface soil (0-20 cm) had a positive and significant correlation (r = 0.91*) with available P content. In sub-surface soil (20-40 cm) available N content was positively and significantly correlated with organic carbon.

Kakar *et al.* (2018b) reported the DTPA-extractable Fe (r = 0.34**), Cu (r = 0.48**) and Zn (r = 0.65**) was significantly and positively related with organic carbon in Saproon valley of Solan district. Kashiwar *et al.* (2018) observed that organic carbon was found to be having positive correlation with available nitrogen, phosphorus, potassium, sulphur, zinc, copper and manganese. Sharma *et al.* (2018a) found organic carbon in the surface and sub-surface soils was significantly and positively correlated with available N and P.

Pandey *et al.* (2019) observed a significant and positive correlation between organic carbon and clay per cent (r = 0.729*). On the other hand, soil organic carbon was inversely correlated with bulk density (r = -0.978**). Available micronutrients such as Zn, Fe, Cu and Mn in soils were significantly and negatively correlated with the soil pH.

2.4 Relationship of soil nutrient contents with plant nutrients

Amuri *et al*. (2017) reported that concentration of K in vegetables was significantly and positively correlated with soil Fe, but negatively correlated with soil pH. Zinc concentration in vegetables was negatively correlated with soil pH. On the other hand, soil P ranged from 4.8 to 145.6 mg kg^{-1} and was significantly and positively correlated with vegetable K, soil pH was significantly and negatively correlated with Cu concentration in vegetables.

Kakar *et al.* (2018a) indicated that the pH of the soils had a negative and significant correlation with leaf Fe (r = -0.65**), Mn (r = -0.51**) and Cu (r = -0.55**) in Saproon valley of Himachal Pradesh. The available P content of the soils registered significant and negative relationship with leaf Ca (r = -0.49*). Available K content in the soils also had a negative and significant correlation with leaf Ca (r = -0.52**) and Mg (r = -0.57**). The exchangeable Mg had a significantly negative correlation with leaf Fe (r = -0.66**) in soils. Available sulphur of surface soils and leaf Fe had significant and positive relationship (r = 0.50*).

Mogta and Sharma (2018) depicted that the leaf N content had positive and significant correlation with soil OC (r = 0.36** and 0.34*), DTPA-extractable Cu (r = 0.34* and 0.26) and DTPA-extractable Zn (r = 0.30* and 0.38**) in both 0-15 cm and 15-30 cm soils, suggesting the soil organic matter as one of the major sources of N for the plant. The leaf Fe was found to be positively correlated with soil N (r = 0.36** and 0.37**) in 0-15 cm and 15-30 cm soils. Leaf Mn content was positively correlated with DTPA-extractable Mn and Cu (r = 0.40** and 0.39**).

Sharma *et al.* (2018a) depicted a correlation between the soil and leaf analysis values showed a significant and positive relationship for N, K, Mg and S for both the surface as well as for sub-surface layers. However, positive and highly significant relationship (r= 0.42**) of S was found only for the surface soil.

MATERIAL AND METHODS

Chapter – 3

MATERIAL AND METHODS

Every scientific study is based on the systematic methodology as it forms edifice on which the scientific validation and precision depends. The present investigation entitled "**Nutritional status of vegetable growing areas of Mandi district of Himachal Pradesh**" was carried out by collecting soil and plant samples to get information on the plant available nutrients and plant nutrient contents. The details of materials used and methodologies employed are presented in this chapter under the following heads:

3.1 General description of study area

3.2 Soil and plant Sampling

3.3 Preparation of soil and plant samples

3.4 Soil analysis

3.5 Plant analysis

3.6 Interpretation of data

3.7 Spatial pattern maps of soil properties and nutrients

3.8 Statistical analysis

3.1 GENERAL DESCRIPTION OF STUDY AREA

Mandi district is located in the western Himalayas, between 31^0 13 '50" and 32^0 04' 30" N latitude and 76^0 37' 20" and 77^0 23' 15" E longitude and altitudes ranging from 651 to 4500 m above mean sea level. The district has a total geographical area of 3,950 square kilometers and constitutes about 7 per cent of the total area of the state. The district is entirely hilly except some area in Sundernagar, Mandi and Chauntra blocks which are fertile valleys. There is a general increase in elevation from west to east and from south to north. The total area under vegetable crops in the district is about 11.109 thousand ha, out of which pea crop occupied an area of about 3.649 thousand ha with an annual production of 55.1 thousand metric tons (Anonymous, 2017b). The major pea growing blocks in the district are Gohar, Sundernagar and Karsog etc. The vegetable crops are produced in the region at a time when they are not available in the plains and, therefore receive a higher premium in the market.

3.1.1 CLIMATE AND RAINFALL

The climate of the district is sub-tropical in the valleys and tends to be temperate near the hilltops. In the higher region, the climate remains cold throughout the year. Average minimum and maximum temperature in the district varies from 3°C to 35°C.

The district receives precipitation in the form of rainfall, mainly during the monsoon period from July to September. The average annual rainfall in the district is about 1331.50 mm. Annual average rainfall from place to place in the district is highly variable and ranges from 700 to more than 2000 mm.

3.1.2 GEOLOGY

Mandi district presents an intricate mosaic of mountain ranges, hills and valleys. The district lies partly on rocks belonging to the central Himalayan zone and some part of district lies on tertiary shales, limestone and sand stone. Two types of soils are mainly observed in the district viz. s*ub-mountainous soil* occurring in Seraj and Karsog blocks and *mountainous soil* occurring in remaining eight blocks of the district. The sub-mountainous soil is high in organic carbon, low in available phosphorous and medium in potash, whereas the mountainous soil is brown in colour, medium in available nitrogen and potash and deficient in available phosphorous. The soil reaction is slightly acidic to neutral and texture in general varies from loam to sandy loam, except in low valley areas being heavy textured.

3.2 SOIL AND PLANT SAMPLING

One hundred thirty five representative soil samples from surface (0-15 cm) and sub-surface (15-30 cm) layers were collected randomly using GPS from forty nine major pea growing villages of Gohar and Sundernagar blocks of the district (Appendix-I) during the month of September - October, 2018 (Figure 3.1). Invariably, two-three soil samples were collected generally from each of the village for surface and sub-surface layers (Figure 3.2 and 3.3). All the samples were collected using stainless steel augar.

The pea leaf samples (135) were also collected in the month of November – December, 2018 from the same field, where the soil samples were collected. Leaf samples from the recent and most developed leaflets were collected at first flowering, as recommended by Kensworthy (1964) and Bhargava and Raghupati (1993).

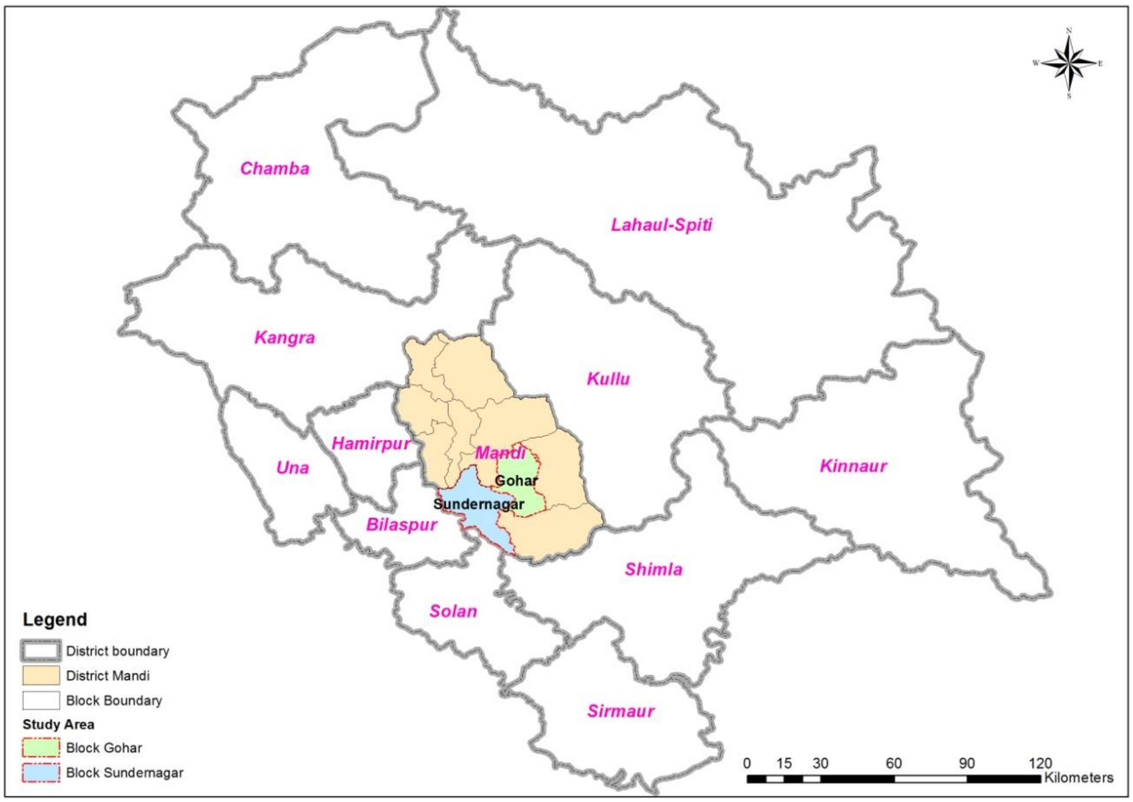

Figure 3.1 Map of the study area

Figure 3.2 View of the sampling area

Figure 3.3 View of the sampling site

3.3 PREPARATION OF SOIL AND PLANT SAMPLES

The soil samples were passed through a 2.0 mm sieve after air-drying and stored in plastic containers. The leaf samples were washed with ordinary water and then with 0.1 N HCl followed by washing with distilled water. They were dried in an oven at 60 ± 5 °C for 72 hours. The dried samples were ground in a steel grinder to facilitate proper mixing of plant material and stored in paper bags for further analysis.

3.4 SOIL ANALYSIS

3.4.1 Soil texture

The texture was determined by hydrometer method and it refers to the relative proportion of sand, silt and clay (%) in a given soil sample (Bouyoucos, 1927). The textural class for respective sample was determined by using textural triangle as suggested by ISSS.

3.4.2 Bulk density

The bulk density was determined by using a metallic core having 10 cm height and 10.5 cm internal diameter (Singh, 1980). The lower end of the core had a sharp edge to facilitate its penetration into the soil and upper end had one cm thick open circular cap fitting on it. The core was driven into the soil with a hammer having a circular base and was then, carefully removed to draw the required volume of soil samples. The bulk density was determined gravimetrically at a temperature of 105 ± 1 ^{o}C to express the bulk density values on dry weight basis.

3.4.3 Soil pH and electrical conductivity (EC)

The soil pH was determined in 1:2 soil : water suspension and the EC of the supernatant solution was recorded by following the procedure outlined by Jackson (1973).

3.4.4 Organic carbon (OC)

It was determined by rapid titration method by Walkley and Black (1934).

3.4.5 Available macronutrient elements

Available nitrogen was determined by alkaline potassium permanganate method of Subbiah and Asija (1956). Available phosphorus was extracted by using 0.5 M $NaHCO_3$ extractant at pH 8.5 (Olsen *et al*., 1954) and determined by $SnCl_2$ reduced ammonium molybdate blue color method (Jackson, 1973). Available potassium was extracted by neutral normal ammonium acetate (Merwin and Peech, 1951) and determined by flame photometer. Exchangeable calcium and magnesium in the ammonium acetate extract were determined by atomic absorption spectrophotometer (Sarma *et al*., 1987). Available sulphur was extracted by morgan's reagent and determined by turbidity method (0.15 % $CaCl_2$) of Chesnin and Yien (1950).

3.4.6 DTPA-extractable cations

The available Fe, Mn, Cu and Zn contents in the soil were extracted using DTPA extractant at pH 7.3 (Lindsay and Norvell, 1978) and determined on atomic absorption spectrophotometer.

3.4.7 Soil nutrient indices

Soil nutrient indices (SNI) were worked out to depict the available status of each macro and micro nutrient by using the following formula proposed by Parker *et al.* (1951) as mention below:

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

Where, NL = number of samples falling in low category of nutrient status

NM = number of samples falling in medium category of nutrient status

NH = number of samples falling in high category of nutrient status

NT = total number of samples analyzed for a given nutrient

3.5 PLANT ANALYSIS

Separate digestion was carried out for nitrogen estimation using concentrated H_2SO_4 and digestion mixture and determined by micro-kjeldhal method as outlined in A.O.A.C. (1970). The prepared leaf samples were digested in a mixture of di-acids HNO_3: $HClO_4$ (4: 1) for P, K, Ca, Mg, S, Fe, Cu, Zn and Mn (Jackson, 1973). Phosphorus in the digest was determined by vanado-molybdate yellow colour method (Jackson, 1973). Potassium and calcium in the digest were determined on flame photometer (Jackson, 1967). Magnesium in the digest was determined on atomic absorption spectrophotometer. Sulphur was determined by turbidimetric method outlined by Chesnin and Yien (1950). Micro-nutrient cations (Fe, Mn, Cu and Zn) were determined on atomic absorption spectrophotometer (Vogel, 1978).

3.6 INTERPRETATION OF DATA

The results of soil analysis were interpreted using the critical limits given in the Table 3.1, 3.2, 3.3, 3.4 and 3.5 and plant analysis results were interpreted using Table 3.6.

A SNI value <1.67, 1.67-2.33 and > 2.33 indicate low, medium and high nutrient status of soils, respectively (Ramamoorthy and Bajaj, 1969).

Table 3.1 Critical limits used for interpretation of bulk density

BD range (g cm^{-3})	Interpretation	Reference
>1.6	Restrict root growth	Mckenzie *et al.* 2004
<1.6	Increase root growth	

Table 3.2 Critical limits used for interpretation of pH

pH range	Denominations
4.0-4.5	Extremely acidic
4.6-5.0	Very strongly acidic
5.1-5.5	Strongly acidic
5.6-6.0	Moderately acidic
6.1-6.5	Slightly acidic
6.6-7.3	Neutral
7.4-7.8	Slightly alkaline

Table 3.3 Critical limits used for interpretation of electrical conductivity

EC (dS m^{-1})	Soil category	Reference
Below 0.8	Normal-suitable for all crops	Raina *et al.* (2007)
0.8-1.6	Critical for salt-sensitive crops	
1.6-2.5	Critical for salt-tolerant crops	
Above 2.5	Injurious to all crops	

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

Sr. No.	Nutrient Element	Soil fertility class			References
		Low	Medium	High	
1.	Organic carbon (g/kg)	<5.0	5.0-15.0	>15.0	Bhandari and Tripathi (1979)
2.	Available N (kg ha^{-1})	< 280.0	280.0-560.0	>560.0	FAI (1977)
3.	Available P (kg ha^{-1})	< 10.0	10.0-24.6	>24.6	FAI (1977)
4.	Available K (kg ha^{-1})	< 108.0	108.0-280.0	> 280.0	Tandon (2009)
Secondary macronutrients					
			Deficient	**Sufficient**	
1.	Available Ca [cmol (p^+) kg^{-1}]		<1.5	>1.5	Tandon (1989)
2.	Available Mg [cmol (p^+) kg^{-1}]		<1.0	>1.0	Tandon (1989)
3.	Available S (mg kg^{-1})		<10.0	>10.0	Tandon (1991)

Table 3.5 Critical limit for available micronutrients (Lindsay and Norvell, 1978)

Availability	Micronutrients (mg kg^{-1})			
	Zn	Cu	Fe	Mn
Low	0.5-1.0	0.1-0.3	2.0-4.0	0.5-1.2
Medium	1.0-3.0	0.3-0.8	4.0-6.0	1.2-3.5
High	3.0-5.0	0.8-3.0	6.0-10.0	3.5-6.0
Very High	>5.0	>3.0	>10.0	>6.0

Table 3.6 Critical limits of nutrients for pea plant samples

Sr. No.	Nutrient element	Concentration			References
		Deficient	Sufficient	High	
	Macronutrient (%)				Mahler *et al.*(1988)
1.	N	< 1.8	1.8-3.4	> 3.4	
2.	P	< 0.23	0.23-0.49	> 0.49	
3.	K	<0.6	0.6-1.4	> 1.4	
4.	Ca	< 0.8	0.8-2.2	> 2.2	
5.	Mg	< 0.1	0.1-0.3	> 0.3	
6.	S	<0.50	0.50-0.70	>0.70	Tandon (2009)
	Micronutrient (ppm)				Mahler *et al.*(1988)
7.	Zn	<25	25-80	>80	
8.	Cu	< 6	6-20	>20	
9.	Fe	<50	50	>50	
10.	Mn	0-25	26-70	>70	Stangel (1969)

3.7 Spatial pattern maps of soil properties and nutrients

In nature the soil properties are highly variable spatially and for accurate estimation of soil properties these continuous variability should be considered. In recent years a new technique called Kriging and its variants were widely recognized as an important spatial interpolation technique in land resource inventories (Hengl *et al.*, 2004). The traditional method of soil analysis and interpretation are laborious, time consuming, hence becoming expensive. With the advancement of GIS and remote sensing technology, predictive soil mapping techniques are introduced. Using inexpensive and readily available ancillary data and indicators that reveal a close relationship to specific soil quantities are being used recently for spatial interpolation.

It is fact that soil properties vary from place to place even within the same field. As a result, the spatial structure can vary at scales that differ by several orders of magnitude from a few meters to hundred kilometers. Such variation with distance can be described well with the help of geo-statistics (Carr and Meyers 1984, Collins and Woodcock 1999). The above phenomena is the best accomplished by the studying the semivariogram (Warrick *et. al.*, 1986) which is a plot of semi-variance that characterizes the rate of change of a mapped variable with respect to distance. Semi-variogram is computed as half the average squared difference between the soil properties of data pairs. The structure of spatial variability was analyzed through semivariograms. Spatial distribution was analyzed through Kriging interpolation using ARCGIS 10.2.1 software. The spatial dependence was analyzed by semi-variogram based on the accepted stationary assumptions which constitute intrinsic hypothesis of regional variable theory (Webster, 1985).

$$S^2 = 1/2\, m \sum_{i=1}^{m} [Z\,(xi) - Z(xi + h)]^2$$

Where, S^2 is the semi variance for m pairs of observations and Z (xi) and Z (xi + h) are observations separated by the distance h usually known as lag.

Parameters defining semi-variogram models are nugget (variability at a smaller scale than the sampling interval and/or sampling and analytical error), sill and range. The range of the semi-variogram is defined as the distance at which the variogram stabilizes around a limiting value, the sill, which can be approximated by the total variance of $Z_{(X)}$. The sill expresses the distance (range) beyond which samples are not correlated.

Kriging of geo-statistics is an optimum interpolation technique for making unbiased estimates of regionalized variables at un-sampled locations in which the structural properties of the semi-variogram and the initial set of samples are used. The spatial prediction of the values of a soil variable Z at an unsampled point X_0 is estimated by the formula (Chile`s and Delfiner, 1999):

$$Z\,(X_0) = \sum_{i=1}^{n} (\lambda i\, Z\,(Xi))$$

Where, X denotes the set of spatial coordinates $\{X_1, X_2\}$, n is the number of neighboring samples and λi are the weights associated with the sampling points Xi. The predicted value $Z(X_0)$ at point X_0 is a weighted average of the values Z at n surrounding points.

In the present study, collected cadastral maps were geo-referenced and identified the sites for sampling. Soil samples were collected from 135 sites and their location are recorded through global position system. Spatial variability maps of soil properties was created using the latitude and longitude and generated by using ARCGIS 10.2.1.

3.8 STATISTICAL ANALYSIS

The data was subjected to statistical analysis to calculate range, mean, standard error and coefficient of variation and establish relationship between soil physical, chemical properties and leaf nutrient contents etc., as per the procedure described by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Chapter – 4

RESULTS AND DISCUSSION

The analysis of data pertaining to soil and plant samples collected from pea growing villages of Gohar and Sundernagar blocks of district Mandi to study the nutrient status is presented in this chapter under following heads;

4.1 Soil fertility status

4.1.1 Physical and chemical properties

4.1.2 Macronutrients

4.1.3 Micronutrients

4.2 Nutrient Indices

4.3 Macronutrients and micronutrients concentration in plants

4.4 Correlation among the soil characteristics and leaf nutrient status

4.1 SOIL FERTILITY STATUS

4.1.1 Soil physical and chemical properties

The perusal of the data in Table 4.1, 4.2 and 4.3 reveals the soil texture, bulk density, soil pH, electrical conductivity (EC) and organic carbon (OC) with respect to vegetable growing areas of Mandi district.

4.1.1.1 Soil texture

The data enumerated in Table 4.1 reveals that sand, silt and clay in 0-15cm soil depth varied from 32.7 to 66.7, 12.0 to 38.3 and 17.2 to 35.3 per cent with mean values of 51.3, 25.2 and 23.5 per cent, respectively. The respective values for 15-30 cm soil depth were 29.6 to 64.7, 12.2 to 38.5 and 17.8 to 36.3 per cent with mean values of 49.2, 25.9 and 24.9 per cent.

In surface samples, the lowest mean sand, silt and clay (36.7, 14.0 and 17.3%) were recorded in Gullas, Laag and Majhar villages under Sundernagar block and highest mean sand, silt and clay (66, 34.1 and 33.4%) were recorded in Kharadhar, Bassi villages under Gohar block and Thamadi village (Sundernagar block), respectively. Whereas, in sub-surface samples, the lowest mean sand, silt and clay (34.6, 15.0 and 18.3%) were recorded in Gullas, Laag and Majhar villages under Sundernagar block and highest mean sand, silt and clay (64.2, 34.6 and

Table 4.1 Soil texture of vegetable growing areas of Mandi district

Sr. No.	Location	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	Majothi	43.6-45.6 (44.9)	41.6-43.6 (42.6)	26.0-30.0 (28.7)	30.0-30.8 (30.4)	24.4-28.4 (26.4)	25.9-30.3 (27.9)	Silty loam and silty clay loam	Silty loam and silty clay loam
2	Bhawanipur	40.7-45.6 (42.6)	38.7-43.6 (41.0)	32.0-34.0 (32.7)	32.4-34.2 (33.1)	22.4-27.3 (24.7)	24.0-28.7 (25.9)	Silty loam and silty clay loam	Silty loam and silty clay loam
3	Kharsi	44.7-46.7 (46.0)	41.7-45.7 (44.0)	28.0-30.0 (29.3)	28.3-31.1 (30.0)	23.3-25.3 (24.6)	24.6-27.2 (25.9)	Silty loam	Silty loam and silty clay loam
4	Thachi	44.7-48.7 (46.7)	42.7-46.6 (45.0)	30.0-34.0 (31.3)	30.6-35.1 (32.2)	21.3-23.3 (22.0)	22.2-23.8 (22.8)	Silty loam	Silty loam
5	Nalahar	42.7-50.7 (46.7)	40.7-48.7 (44.7)	30.0-34.0 (32.7)	31.1-34.4 (33.2)	19.3-23.3 (20.6)	20.2-25.0 (22.1)	Silty loam	Silty loam
6	Sheladhar	54.7-58.7 (56.0)	52.6-56.7 (54.3)	24.0-26.0 (24.7)	24.7-24.6 (25.2)	17.3-21.3 (19.3)	18.6-22.8 (20.5)	Silty loam and loam	Silty loam and loam
7	Deem	44.7-50.7 (48.0)	43.6-49.6 (46.6)	28.0-34.0 (30.7)	28.1-34.2 (30.9)	21.3-21.3 (21.3)	22.2-22.9 (22.5)	Silty loam	Silty loam
8	Bassi	38.7-42.7 (41.3)	36.6-41.7 (39.6)	32.0-38.3 (34.1)	32.2-38.5 (34.4)	23.3-25.3 (24.6)	24.9-26.8 (25.9)	Silty loam	Silty loam and silty clay loam
9	Duga	44.7-46.7 (45.7)	42.6-44.6 (43.6)	33.8-34.1 (34.0)	34.5-34.6 (34.6)	19.3-21.3 (20.3)	20.9-22.8 (21.8)	Silty loam	Silty loam
10	Kotla	50.7-52.7 (51.4)	47.7-50.7 (49.0)	26.0-32.0 (28.7)	26.5-32.7 (29.4)	17.3-21.3 (19.9)	18.7-23.4 (21.6)	Silty loam	Silty loam
11	Bhava	46.7-54.7 (52.0)	45.6-52.7 (50.0)	24.0-30.0 (26.7)	24.3-30.6 (27.1)	19.3-23.3 (21.3)	20.8-24.1 (22.9)	Silty loam and loam	Silty loam and loam
12	Daan	42.7-46.7 (44.7)	40.6-43.7 (42.3)	30.0-34.0 (32.0)	30.6-34.1 (32.3)	21.3-25.3 (23.3)	24.1-26.8 (25.4)	Silty loam	Silty loam and clay loam
13	Taneli	42.7-44.7 (44.0)	40.6-43.7 (42.3)	30.0-32.0 (31.3)	30.4-32.4 (31.7)	23.3-25.3 (24.7)	24.9-27.1 (26)	Silty loam	Silty loam and silty clay loam
14	Gohar	62.7-66.7 (64.7)	58.7-62.6 (60.6)	12.0-16.0 (14.7)	12.2-16.6 (15.1)	19.3-21.3 (20.6)	23.0-25.2 (24.3)	Loam	Loam
15	Khayod	32.7-42.7 (38.7)	29.6-40.7 (36.6)	28.0-36.0 (31.3)	29.0-36.5 (32.1)	29.3-31.3 (30.0)	29.7-33.9 (31.3)	Silty clay loam	Silty clay loam
16	Dari	36.7-40.7 (39.4)	33.7-38.6 (36.6)	26.0-32.0 (28.7)	27.2-32.5 (29.5)	31.3-33.3 (31.9)	33.8-34.2 (33.9)	Silty clay loam	Silty clay loam
17	Masog	42.7-48.7 (46.0)	40.6-46.7 (44.3)	22.0-30.0 (26.0)	22.4-30.1 (26.2)	27.3-29.3 (28.0)	28.2-30.9 (29.5)	Silty clay loam and clay loam	Silty clay loam and clay loam

18	Chachyot	50.7-54.7 (53.4)	48.7-52.6 (50.7)	20.0-26.0 (22.0)	20.3-26.3 (22.4)	23.3-25.3 (24.6)	25.0-29.0 (26.9)	Clay loam and silty loam	Clay loam and silty loam
19	Bharjodu	50.7-54.7 (52.0)	47.7-51.7 (49.7)	22.0-24.0 (23.3)	22.7-24.8 (24.0)	23.3-25.3 (24.7)	25.6-27.5 (26.3)	Loam	Clay loam and loam
20	Kot	46.7-52.7 (50.7)	44.6-51.7 (49.0)	22.0-30.0 (25.3)	22.4-31.0 (25.9)	23.3-25.3 (24.0)	24.1-27.0 (25.1)	Loam and silty loam	Clay loam, loam and silty loam
21	Naugraun	52.7-58.7 (55.4)	50.6-56.6 (53.6)	16.0-20.0 (17.3)	16.2-21.0 (18.1)	25.3-29.3 (27.3)	26.4-30.1 (28.3)	Clay loam and loam	Clay loam
22	Saloyi	48.7-60.7 (56.0)	46.6-58.7 (54.0)	14.0-22.0 (17.4)	15.0-22.3 (18.1)	23.3-29.3 (26.6)	24.3-31.1 (27.9)	Clay loam and loam	Clay loam and loam
23	Kutwachi	54.7-62.7 (59.4)	52.6-58.7 (56.0)	16.0-22.0 (18.7)	18.0-23.0 (20.3)	21.3-23.3 (22.0)	23.3-24.4 (23.7)	Loam	Loam
24	Kharadhar	64.7-66.7 (66.0)	62.6-64.7 (63.3)	15.9-16.2 (16.0)	16.2-17.0 (16.7)	17.3-19.3 (18.0)	18.3-21.2 (20.0)	Loam	Loam
25	Sakor	40.7-42.7 (41.7)	38.6-40.7 (39.6)	24.0-28.0 (27.0)	25.0-29.0 (28.0)	29.3-33.3 (31.3)	30.4-34.3 (32.4)	Silty clay loam and clay loam	Silty clay loam and clay loam
26	Sangli	50.7-62.7 (57.2)	48.7-60.6 (55.1)	20.0-22.0 (21.0)	21.0-23.0 (22.0)	17.3-27.3 (21.8)	18.4-28.3 (22.9)	Loam and clay loam	Loam and clay loam
27	Thamadi	38.7-42.7 (40.6)	36.6-40.7 (38.6)	25.8-26.0 (26.0)	26.0-27.1 (27.0)	31.3-35.3 (33.4)	32.3-36.3 (34.3)	Silty clay loam	Silty clay loam
28	Chuni	38.7-46.7 (42.0)	36.6-44.6 (40.0)	26.0-32.0 (30.0)	27.0-33.0 (31.0)	27.3-29.3 (28.0)	28.3-30.4 (29.0)	Silty clay loam	Silty clay loam
29	Rohanda	50.7-52.7 (52.0)	49.6-52.6 (51.3)	27.9-28.2 (28.0)	28.1-28.3 (28.2)	19.3-21.3 (20.0)	19.3-22.1 (20.5)	Silty clay loam	Silty clay loam
30	Ghasnu	46.7-50.7 (49.4)	45.6-49.7 (48.0)	23.9-24.3 (24.0)	24.1-24.5 (24.3)	25.3-29.3 (26.6)	26-30.3 (27.7)	Loam and clay loam	Loam and clay loam
31	Kamand	46.7-50.7 (48.0)	45.6-48.6 (46.6)	24.0-32.0 (28.7)	25.0-32.2 (29.3)	21.3-25.3 (23.3)	22.2-26.4 (24.1)	Silty loam and loam	Silty loam and clay loam
32	Kathel	62.7-64.7 (64.0)	61.6-62.7 (62.3)	14.0-18.0 (16.0)	15.0-19.0 (16.8)	17.3-21.3 (20.0)	18.3-22.4 (20.9)	Loam	Loam
33	Okhal	50.7-54.7 (52.7)	49.7-53.7 (51.3)	23.9-24.3 (24.0)	24.3-25.0 (24.6)	21.3-25.3 (23.3)	21.9-26.0 (24.1)	Loam	Loam and clay loam
34	Majhar	58.7-66.6 (62.7)	57.7-64.6 (61.2)	16.0-24.0 (20.0)	17.0-24.1 (20.6)	17.2-17.3 (17.3)	18.2-18.4 (18.3)	Loam	Loam
35	Majhothi	52.7-54.7 (53.4)	50.6-53.7 (51.6)	20.0-26.0 (23.3)	20.4-27.0 (23.9)	21.3-25.3 (23.3)	22.4-25.9 (24.5)	Loam and silty loam	Loam and silty loam
36	Rohangalu	54.7-58.7 (56.7)	52.6-56.7 (54.7)	20.0-24.0 (21.3)	21.0-25.0 (22.3)	19.3-25.3 (22.0)	20.4-26.4 (23.0)	Loam	Loam and clay loam

37	Laag	60.7-62.7 (61.7)	59.6-60.7 (60.1)	13.8-14.1 (14.0)	14.9-15.1 (15.0)	23.3-25.3 (24.3)	24.3-25.4 (24.9)	Loam	Loam
38	Nalni	62.7-64.7 (63.7)	61.6-62.6 (62.1)	17.8-18.2 (18.0)	18.7-19.3 (19.0)	17.3-19.3 (18.3)	18.4-19.4 (18.9)	Loam	Loam
39	Dol	46.6-46.8 (46.7)	44.6-45.7 (45.1)	30.0-32.0 (31.0)	30.3-33.0 (31.7)	21.3-23.3 (22.3)	22.4-24.0 (23.2)	Silty loam	Silty loam
40	Dharli	44.7-46.7 (45.7)	42.6-44.7 (43.7)	31.8-32.2 (32.0)	32.9-33.1 (33.0)	21.3-23.3 (22.3)	22.3-24.4 (23.3)	Silty loam	Silty loam
41	Ghurangalu	56.7-60.7 (58.7)	54.6-59.6 (57.1)	22.0-24.0 (23.0)	22.1-25.0 (23.6)	17.3-19.3 (18.3)	18.3-20.4 (19.3)	Loam	Loam
42	Jai Devi	64.7-66.7 (65.7)	63.7-64.7 (64.2)	14.0-18.0 (16.0)	15.0-18.5 (16.8)	17.3-19.3 (18.3)	17.8-20.3 (19.0)	Loam	Loam
43	Kandyah	44.7-50.7 (47.4)	42.6-49.6 (45.6)	25.0-30.0 (29.3)	28.3-31.0 (30.1)	21.3-25.3 (23.3)	22.1-26.4 (24.3)	Silty loam	Silty loam ad Silty clay loam
44	Chatar	54.7-56.7 (56.0)	52.3-54.7 (53.9)	25.8-26.2 (26.0)	26.9-27.1 (27.0)	17.3-19.3 (18.0)	18.3-20.7 (19.1)	Silty loam	Silty loam
45	Rada	56.7-60.7 (58.7)	54.6-59.3 (56.7)	19.9-20.1 (20.0)	20.9-21.2 (21.0)	19.3-23.3 (21.3)	19.7-24.4 (22.3)	Loam	Loam
46	Khilra	58.7-60.7 (60.0)	58.3-58.6 (58.4)	16.0-18.0 (16.7)	16.2-19.0 (17.4)	21.3-25.3 (23.3)	22.4-25.5 (24.2)	Loam	Loam
47	Maun	54.7	52.6	24.0	25.0	21.3	22.4	Loam	Loam
48	Gullas	36.7	34.6	30.0	31.0	33.3	34.4	Silty clay loam	Silty clay loam
49	Ghiri	50.7	48.7	24.0	25.0	25.3	26.3	Loam	Clay loam
	Range	**32.7-66.7**	**29.6-64.7**	**12.0-38.3**	**12.2-38.5**	**17.2-35.3**	**17.8-36.3**		
	Mean	**51.3**	**49.2**	**25.2**	**25.9**	**23.5**	**24.9**		
	SE (±)	**0.68**	**0.68**	**0.51**	**0.51**	**0.36**	**0.36**		
	CV (%)	**15.44**	**15.95**	**23.68**	**22.74**	**17.57**	**16.88**		

**Values in parenthesis indicate mean*

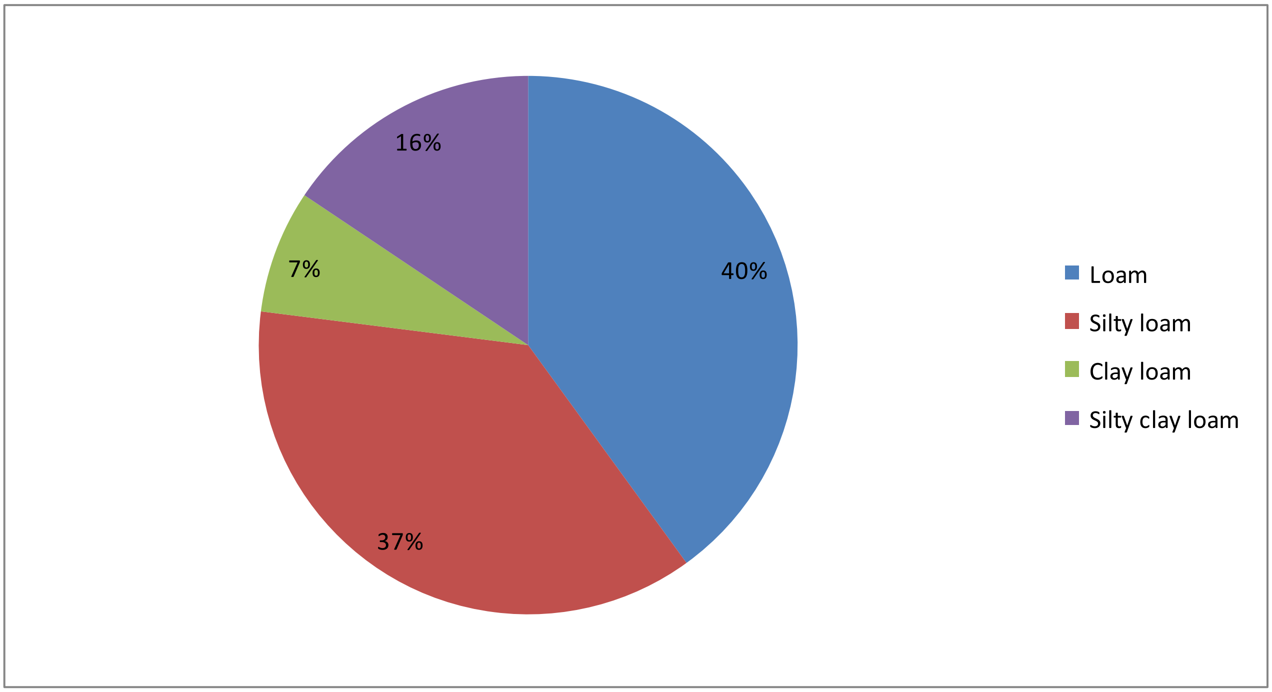

Figure 4.1 Per cent distribution of textural classes in surface depth (0-15cm)

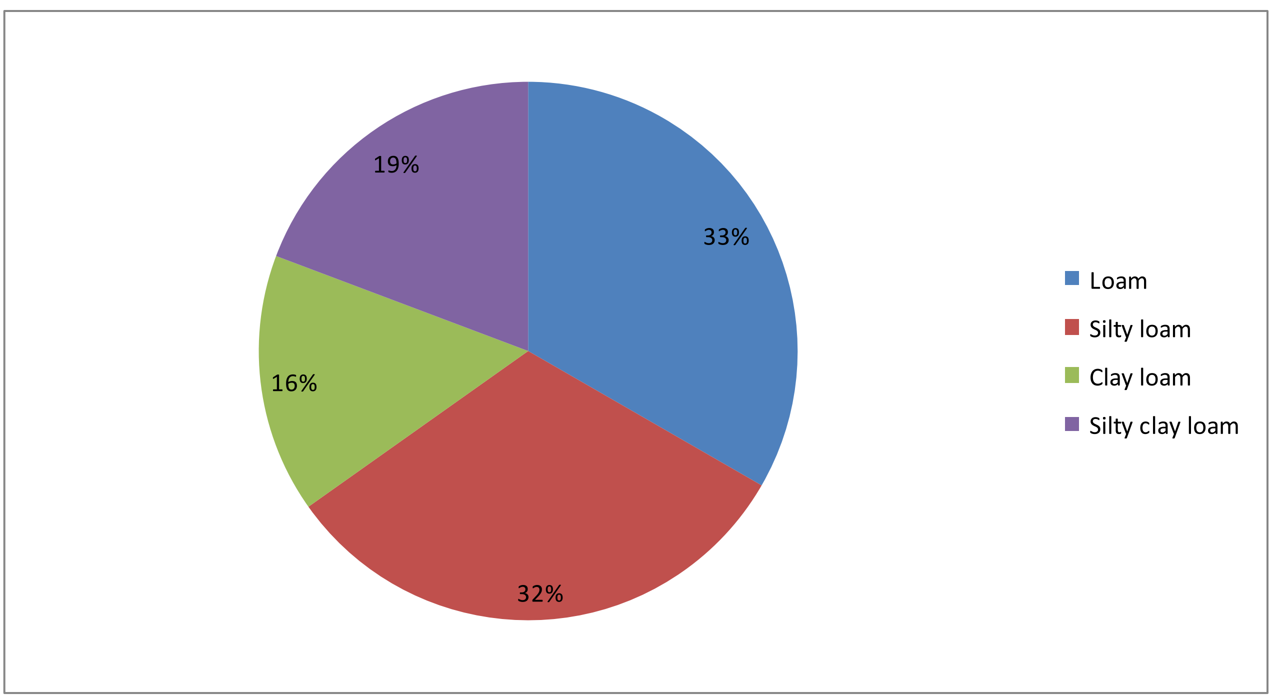

Figure 4.2 Per cent distribution of textural classes in sub-surface depth (15-30cm)

34.4%) were recorded in Jai Devi (Sundernagar block), Duga village (Gohar block) and Gullas village (Sundernagar block), respectively.

Considering the cumulative range data depicted in Table 4.1, it revealed that there was a decline in the percentage of sand and increase in percentage of silt and clay with increase in soil depth, indicating migration of finer soil fractions to lower depths under the effect of climatic conditions of the region (Figure 4.1 and 4.2). The higher clay content in the sub-surface layer may be ascribed to the downward translocation of clay under higher rainfall conditions and due to development of textural B horizons (Gupta and Verma, 1992). The results are in line with the findings of Sharma and Bhandari (1992) and Jamio (2014).

On the basis of soil textural classes, soils of different locations under investigation were identified as silty loam, loam, silty clay loam and clay loam.

4.1.1.2 Bulk density (BD)

Bulk density of pea growing soils ranged from 1.02 to 1.30 g cm^{-3} and 1.07 to 1.38 g cm^{-3} with mean values of 1.18 g cm^{-3} and 1.26 g cm^{-3} in surface and sub-surface samples, respectively (Table 4.2). The lowest and highest mean BD in surface samples were recorded in Nalahar (1.05 g cm^{-3}) and Kharadhar (1.29 g cm^{-3}) villages under Gohar block, respectively. Whereas, in sub-surface samples, the lowest and highest mean BD were recorded in Nalahar (1.10 g cm^{-3}) village (Gohar block) and Kandyah (1.36 g cm^{-3}) village under Sundernagar block, respectively. The spatial distribution map of BD of pea growing areas is presented in Figure 4.3.

The bulk density of the surface and sub-surface soil sample is < 1.6 g cm^{-3}, hence the soils are less compact and does not interfere with root growth (Table 3.1). Therefore, soil is good for the cultivation of vegetable crops. Similar results were also reported by Kyandiah (2012) and Chandel *et al.* (2017). Generally, bulk density increases with increasing sand and rock content and decreases with increasing organic matter content.

4.1.1.3 Soil pH

The pH of the soils of selected pea growing villages of two blocks of Mandi district of Himachal Pradesh ranged from 4.4 to 7.7 (extremely acidic to slightly alkaline) and 4.7 to 7.7 (very strongly acidic to slightly alkaline) with mean values of 6.15 and 6.18 in surface and sub-surface layers, respectively (Table 4.3). The lowest mean value of 4.9 in surface soil samples was recorded in Kharadhar village (Gohar block) and highest value of 7.5 in Nalni village under

Table 4.2 Bulk density (BD) of vegetable growing soils of Mandi district

Sr. No.	Location	BD (g cm^{-3})	BD (g cm^{-3})
		Soil depth (cm)	
		0-15	15-30
1	Majothi	1.16-1.17 (1.17)	1.19-1.22 (1.20)
2	Bhawanipur	1.02-1.10 (1.06)	1.07-1.14 (1.11)
3	Kharsi	1.08-1.14 (1.11)	1.14-1.16 (1.15)
4	Thachi	1.19-1.23 (1.21)	1.21-1.30 (1.25)
5	Nalahar	1.03-1.07 (1.05)	1.08-1.13 (1.10)
6	Sheladhar	1.12-1.17 (1.15)	1.16-1.20 (1.18)
7	Deem	1.06-1.07 (1.06)	1.12-1.18 (1.15)
8	Bassi	1.20-1.23 (1.21)	1.24-1.31 (1.28)
9	Duga	1.09-1.10 (1.10)	1.14-1.18 (1.16)
10	Kotla	1.05-1.12 (1.09)	1.11-1.20 (1.16)
11	Bhava	1.23-1.28 (1.25)	1.26-1.36 (1.30)
12	Daan	1.23-1.27 (1.25)	1.29-1.35 (1.32)
13	Taneli	1.22-1.26 (1.24)	1.30-1.33 (1.32)
14	Gohar	1.15-1.18 (1.16)	1.22-1.23 (1.23)
15	Khayod	1.05-1.08 (1.06)	1.12-1.18 (1.14)
16	Dari	1.08-1.11 (1.09)	1.17-1.19 (1.18)
17	Masog	1.06-1.09 (1.08)	1.17-1.21 (1.19)
18	Chachyot	1.15-1.16 (1.16)	1.20-1.23 (1.22)
19	Bharjodu	1.21-1.29 (1.25)	1.30-1.35 (1.32)
20	Kot	1.21-1.28 (1.25)	1.31-1.38 (1.35)
21	Naugraun	1.22-1.24 (1.23)	1.29-1.33 (1.32)
22	Saloyi	1.21-1.24 (1.23)	1.28-1.32 (1.30)
23	Kutwachi	1.18-1.21 (1.20)	1.29-1.32 (1.30)
24	Kharadhar	1.28-1.30 (1.29)	1.34-1.36 (1.35)

25	Sakor	1.08-1.14 (1.12)	1.13-1.20 (1.17)
26	Sangli	1.10-1.12 (1.11)	1.18-1.28 (1.22)
27	Thamadi	1.12-1.17 (1.15)	1.21-1.22 (1.22)
28	Chuni	1.18-1.21 (1.19)	1.24-1.29 (1.27)
29	Rohanda	1.20-1.22 (1.21)	1.32-1.34 (1.33)
30	Ghasnu	1.18-1.20 (1.19)	1.26-1.31 (1.28)
31	Kamand	1.16-1.20 (1.18)	1.29-1.32 (1.31)
32	Kathel	1.16-1.19 (1.18)	1.27-1.31 (1.29)
33	Okhal	1.17-1.20 (1.18)	1.20-1.29 (1.24)
34	Majhar	1.12-1.15 (1.14)	1.22-1.26 (1.24)
35	Majhothi	1.07-1.14 (1.11)	1.16-1.27 (1.21)
36	Rohangalu	1.15-1.19 (1.17)	1.25-1.28 (1.26)
37	Laag	1.27-1.29 (1.28)	1.27-1.37 (1.32)
38	Nalni	1.27-1.28 (1.28)	1.30-1.34 (1.32)
39	Dol	1.24-1.25 (1.25)	1.32-1.33 (1.33)
40	Dharli	1.20-1.24 (1.22)	1.32-1.35 (1.34)
41	Ghurangalu	1.22-1.25 (1.24)	1.29-1.32 (1.31)
42	Jai Devi	1.20-1.25 (1.23)	1.34-1.36 (1.35)
43	Kandyah	1.23-1.27 (1.25)	1.35-1.36 (1.36)
44	Chatar	1.21-1.25 (1.24)	1.28-1.37 (1.33)
45	Rada	1.20-1.27 (1.24)	1.29-1.37 (1.34)
46	Khilra	1.20-1.25 (1.22)	1.29-1.34 (1.32)
47	Maun	1.16	1.30
48	Gullas	1.10	1.20
49	Ghiri	1.13	1.24
	Range	**1.02-1.30**	**1.07-1.38**
	Mean	**1.18**	**1.26**
	SE (±)	**0.01**	**0.01**
	CV (%)	**5.82**	**6.06**

**Values in parenthesis indicate mean*

Sundernagar block. In sub-surface soils, Kharadhar village under Gohar block recorded the lowest mean pH value of 5.0 and highest mean pH value of 7.5 was recorded in Laag village under Sundernagar block. The soil reaction indicates increasing trends with soil depth. The soils of district are acidic to neutral in soil reaction (Table 3.2). The spatial distribution map of soil pH of pea growing areas is presented in Figure 4.4.

The variation in soil pH in pea growing areas could be attributed to leaching of bases, rainfall, continuous decaying of organic matter and high iron, manganese and aluminum content. The soils of the study area were found acidic to neutral in soil reaction which corroborate the findings of Chander *et al.* (2014) who also observed similar trends in mid hills sub-humid zone of Himachal Pradesh. Kumar and Paliyal (2018) while investigating the soils under different crops in Mandi district and reported that these soils were acidic because of their location at relatively higher altitude and also higher amount of organic carbon in the surface horizon. Soil pH exhibited an increasing trend with increase in the depth of soil which may be due to presence of higher amount of exchangeable calcium and lower amount of organic matter in sub-surface soils.

4.1.1.4 Electrical conductivity (EC)

A perusal of data (Table 4.3) on electrical conductivity indicates that its values in surface soils ranged from 0.013 to 0.185 dS m^{-1}, with a mean value of 0.07 dS m^{-1}. The sub-surface samples recorded lower values ranging from 0.017 to 0.155 dS m^{-1}, with a mean value of 0.06 dS m^{-1}. The lowest (0.019 dS m^{-1} and 0.019 dS m^{-1}) and highest (0.154 dS m^{-1} and 0.127 dS m^{-1}) mean values of EC in surface and sub-surface samples were recorded in Sheladhar village under Gohar block and Laag village under Sundernagar block, respectively. The spatial distribution map of electrical conductivity of pea growing areas is presented in Figure 4.5.

In light of the suggested EC value < 0.8 dS m^{-1} is considered as normal and suitable for all crops, the pea growing soils of the district were in safe limits (Table 3.3). A high value of EC was obtained for surface layer depicted that there is accumulation of salts in the surface. The results are in agreement with those obtained by Verma and Tripathi (2007) who found that the soils of Himachal Pradesh are very low in soluble salt concentration with EC value ranging from 0.01 to 0.15 dS m^{-1}. Similar results were also observed by Vijayakumar *et al.* (2011) and Sharma and Sood (2019).

Table 4.3 Soil pH, electrical conductivity (EC) and organic carbon (OC) in vegetable growing areas of Mandi district

Sr.No.	Location	Soil pH		Soil EC (dS m^{-1})		Organic carbon (g kg^{-1})	
		Soil depth (cm)					
		0-15	15-30	0-15	15-30	0-15	15-30
1	Majothi	5.8-6.1 (6.0)	6.0-6.1 (6.0)	0.039-0.050 (0.044)	0.018-0.032 (0.025)	17.9-24.7 (21.7)	11.9-18.9 (15.4)
2	Bhawanipur	5.6-5.8 (5.8)	5.6-5.7 (5.6)	0.038-0.044 (0.041)	0.038-0.042 (0.040)	19.4-26.0 (23.6)	20.4-23.2 (22.0)
3	Kharsi	6.2-6.5 (6.3)	5.9-6.3 (6.1)	0.044-0.076 (0.061)	0.055-0.065 (0.061)	16.5-20.9 (18.5)	14.1-15.3 (14.6)
4	Thachi	6.0-6.7 (6.4)	5.9-6.5 (6.1)	0.076-0.124 (0.096)	0.050-0.112 (0.080)	12.0-21.3 (16.7)	9.8-17.4 (13.2)
5	Nalahar	5.2-5.8 (5.5)	5.5-5.7 (5.6)	0.032-0.063 (0.045)	0.020-0.030 (0.025)	16.4-19.2 (17.9)	15.8-19.7 (18.0)
6	Sheladhar	5.0-5.4 (5.2)	5.1-5.3 (5.2)	0.017-0.020 (0.019)	0.017-0.022 (0.019)	12.0-13.5 (13.0)	9.6-13.4 (11.3)
7	Deem	5-5.4 (5.2)	5.1-5.5 (5.3)	0.036-0.051 (0.045)	0.036-0.040 (0.037)	16.1-16.5 (16.3)	12.8-14.6 (13.8)
8	Bassi	6.9-7.1 (7.0)	7.0-7.2 (7.1)	0.065-0.086 (0.077)	0.060-0.068 (0.065)	5.25-14.25 (11.2)	3.8-14.6 (10.7)
9	Duga	5.7-6.5 (6.1)	5.8-6.2 (6.0)	0.035-0.067 (0.051)	0.041-0.044 (0.043)	12.8-18.8 (15.8)	8.6-13.4 (11.0)
10	Kotla	5.8-6.5 (6.2)	5.8-6.6 (6.2)	0.025-0.059 (0.041)	0.038-0.057 (0.048)	12.6-17.0 (15.2)	11.7-14.6 (12.8)
11	Bhava	6.6-6.8 (6.6)	6.4-6.6 (6.5)	0.030-0.053 (0.04)	0.027-0.064 (0.047)	8.3-26.9 (18.9)	5.6-8.7 (7.0)
12	Daan	6.0-6.7 (6.3)	6.0-6.9 (6.3)	0.052-0.073 (0.063)	0.051-0.083 (0.064)	22.7-24.3 (23.5)	18.6-22.5 (20.6)
13	Taneli	5.2-5.5 (5.4)	5.2-5.6 (5.4)	0.057-0.085 (0.070)	0.037-0.121 (0.068)	11.6-22.5 (16.0)	9.0-10.5 (9.7)
14	Gohar	5.1-5.5 (5.3)	5.1-5.3 (5.2)	0.029-0.055 (0.039)	0.026-0.073 (0.056)	10.5-17.0 (13.1)	6.2-14.9 (10.8)
15	Khayod	5.2-5.4 (5.3)	5.3-5.5 (5.4)	0.024-0.055 (0.043)	0.025-0.071 (0.047)	9.3-12.3 (11.0)	6.6-9.9 (8.7)
16	Dari	5.7-5.9 (5.8)	5.8-6.0 (5.9)	0.040-0.062 (0.049)	0.029-0.042 (0.037)	9.8-12.5 (10.8)	7.5-11.4 (9.7)
17	Masog	7.3-7.4 (7.3)	7.0-7.3 (7.2)	0.066-0.107 (0.080)	0.093-0.123 (0.112)	5.6-8.4 (6.7)	5.7-10.2 (7.6)
18	Chachyot	6.3-6.5 (6.4)	6.4-6.6 (6.5)	0.046-0.077 (0.065)	0.042-0.072 (0.056)	2.6-6 (4.5)	3.5-4.5 (4.0)
19	Bharjodu	4.4-5.6 (5.0)	4.7-5.7 (5.2)	0.055-0.075 (0.063)	0.056-0.072 (0.065)	10.2-18.2 (14.0)	9.2-12.6 (11.1)
20	Kot	5.8-6.7 (6.1)	6.3-6.9 (6.5)	0.027-0.089 (0.065)	0.057-0.089 (0.069)	11.1-15.2 (13.5)	8.3-11.0 (9.2)
21	Naugraun	5.3-5.5 (5.4)	5.2-5.3 (5.2)	0.021-0.114 (0.055)	0.034-0.085 (0.056)	9.9-12.75 (11.1)	9.5-11.4 (10.2)
22	Saloyi	5.7-6.5 (6.0)	5.7-6.1 (5.8)	0.067-0.089 (0.081)	0.042-0.125 (0.084)	13.1-15.8 (14.0)	9.6-12.2 (11.2)
23	Kutwachi	5.9-6.1 (6.0)	5.9-6.3 (6.1)	0.069-0.086 (0.078)	0.044-0.116 (0.080)	19.2-14.8 (21.3)	11.4-24.0 (16.4)
24	Kharadhar	4.9-5.1 (4.9)	4.8-5.2 (5.0)	0.042-0.089 (0.071)	0.050-0.062 (0.058)	6.0-9.2 (8.0)	5.7-7.2 (6.2)

25	Sakor	5.9-6.6 (6.3)	6.0-6.5 (6.2)	0.038-0.053 (0.048)	0.035-0.054 (0.042)	3.3-10.2 (6.3)	3.8-5.3 (4.2)
26	Sangli	6.3-6.5 (6.4)	6.2-6.5 (6.3)	0.044-0.082 (0.066)	0.033-0.079 (0.056)	2.9-16.7 (9.0)	3.6-15.6 (8.6)
27	Thamadi	6.0-6.2 (6.1)	6.0-6.3 (6.1)	0.023-0.106 (0.071)	0.027-0.137 (0.085)	4.8-11.0 (8.2)	3.9-7.7 (6.1)
28	Chuni	6.2-6.4 (6.3)	6.2-6.5 (6.4)	0.036-0.084 (0.062)	0.038-0.099 (0.078)	9.8-18.5 (13.8)	9.6-15.8 (11.9)
29	Rohanda	5.6-5.8 (5.7)	5.6-6.0 (5.7)	0.046-0.081 (0.070)	0.048-0.073 (0.058)	12.2-20.3 (16.7)	14.4-22.1 (17.8)
30	Ghasnu	6.1-7.0 (6.6)	6.3-6.8 (6.5)	0.068-0.152 (0.100)	0.053-0.092 (0.072)	5.1-21.2 (14.2)	4.5-10.4 (6.7)
31	Kamand	6.2-6.3 (6.3)	6.2-6.4 (6.3)	0.093-0.144 (0.111)	0.045-0.101 (0.08)	9.5-17.6 (13.5)	9.9-11.3 (10.5)
32	Kathel	5.3-5.8 (5.6)	5.4-5.9 (5.7)	0.013-0.118 (0.079)	0.047-0.123 (0.075)	12.5-15.8 (14.0)	5.9-14.9 (9.3)
33	Okhal	6.2-7.0 (6.6)	6.0-7.0 (6.6)	0.090-0.099 (0.096)	0.079-0.145 (0.116)	13.4-20.3 (16.8)	12.8-15.8 (14.2)
34	Majhar	5.7-6.0 (5.9)	5.6-6.2 (5.9)	0.048-0.063 (0.055)	0.042-0.043 (0.042)	9.6-17.4 (13.5)	8.1-17.4 (12.8)
35	Majhothi	5.8-6.5 (6.2)	6.0-6.6 (6.3)	0.060-0.098 (0.082)	0.055-0.090 (0.075)	11.0-21.2 (16.7)	9.5-20.4 (14.5)
36	Rohangalu	5.9-6.7 (6.2)	5.8-6.4 (6.1)	0.090-0.185 (0.127)	0.044-0.155 (0.088)	5.7-15.9 (11.8)	3.8-15.3 (10.5)
37	Laag	7.2-7.4 (7.3)	7.4-7.6 (7.5)	0.125-0.184 (0.154)	0.12-0.134 (0.127)	9.3-11.3 (10.3)	8.3-10.2 (9.2)
38	Nalni	7.3-7.6 (7.5)	7.2-7.5 (7.4)	0.090-0.121 (0.105)	0.091-0.124 (0.108)	11.7-20.4 (16.0)	12.6-18.6 (15.6)
39	Dol	5.5-6.0 (5.8)	5.7-6.3 (6.0)	0.024-0.031 (0.028)	0.022-0.055 (0.038)	8.6-11.7 (10.1)	8.3-11.0 (9.6)
40	Dharli	6.8-7.0 (6.9)	6.5-6.9 (6.7)	0.072-0.075 (0.074)	0.062-0.085 (0.073)	15.3-20.1 (17.7)	11.1-17.4 (14.3)
41	Ghurangalu	6.4-7.1 (6.8)	6.7-7.3 (7.0)	0.037-0.095 (0.066)	0.047-0.080 (0.063)	9.6-17.9 (13.7)	8.7-11.5 (10.1)
42	Jai Devi	6.1-7.4 (6.7)	6.5-7.3 (6.9)	0.033-0.057 (0.045)	0.060-0.098 (0.079)	5.7-8.7 (7.2)	5.7-7.4 (6.5)
43	Kandyah	7.2-7.4 (7.3)	7.3-7.5 (7.4)	0.069-0.129 (0.103)	0.068-0.132 (0.091)	6.2-12.5 (8.6)	5.3-9.8 (7.3)
44	Chatar	7.0-7.1 (7.1)	7.2-7.3 (7.2)	0.082-0.134 (0.112)	0.090-0.120 (0.107)	4.4-8.3 (6.3)	5.1-7.7 (6.4)
45	Rada	6.8-7.7 (7.3)	6.9-7.7 (7.4)	0.123-0.134 (0.125)	0.082-0.089 (0.086)	10.7-20.3 (17.1)	9.1-20.1 (16.3)
46	Khilra	6.1-6.5 (6.3)	6.2-6.4 (6.3)	0.024-0.034 (0.029)	0.018-0.025 (0.021)	20.1-20.4 (20.3)	19.5-20.3 (19.9)
47	Maun	5.0	5.1	0.076	0.073	14.6	23.0
48	Gullas	6.3	6.0	0.045	0.045	6.0	5.5
49	Ghiri	5.5	5.6	0.036	0.049	20.6	17.8
	Range	**4.4-7.7**	**4.7-7.7**	**0.013-0.185**	**0.017-0.155**	**2.6-26.9**	**3.5-24.0**
	Mean	**6.15**	**6.18**	**0.07**	**0.06**	**13.8**	**11.5**
	SE (±)	**0.06**	**0.06**	**0.003**	**0.003**	**0.5**	**0.4**
	CV (%)	**11.17**	**11.04**	**48.88**	**48.38**	**41.1**	**44.8**

**Values in parenthesis indicate mean*

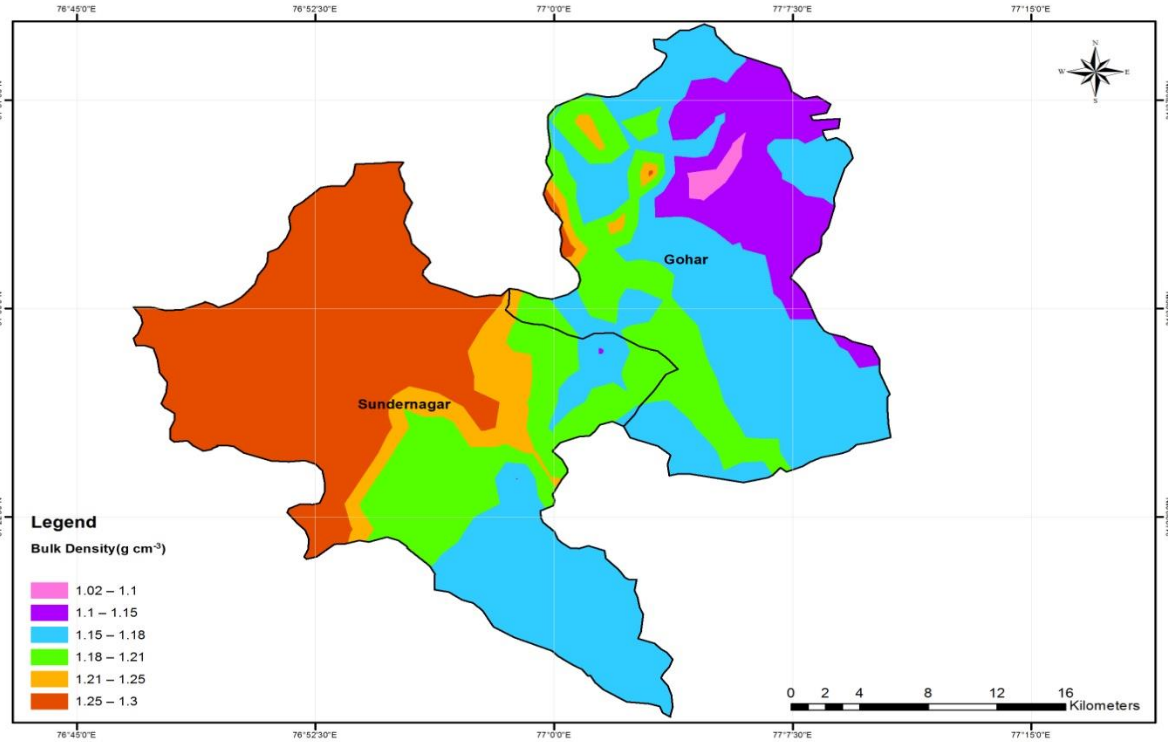

Figure 4.3 Spatial distribution map of soil bulk density (0-15cm)

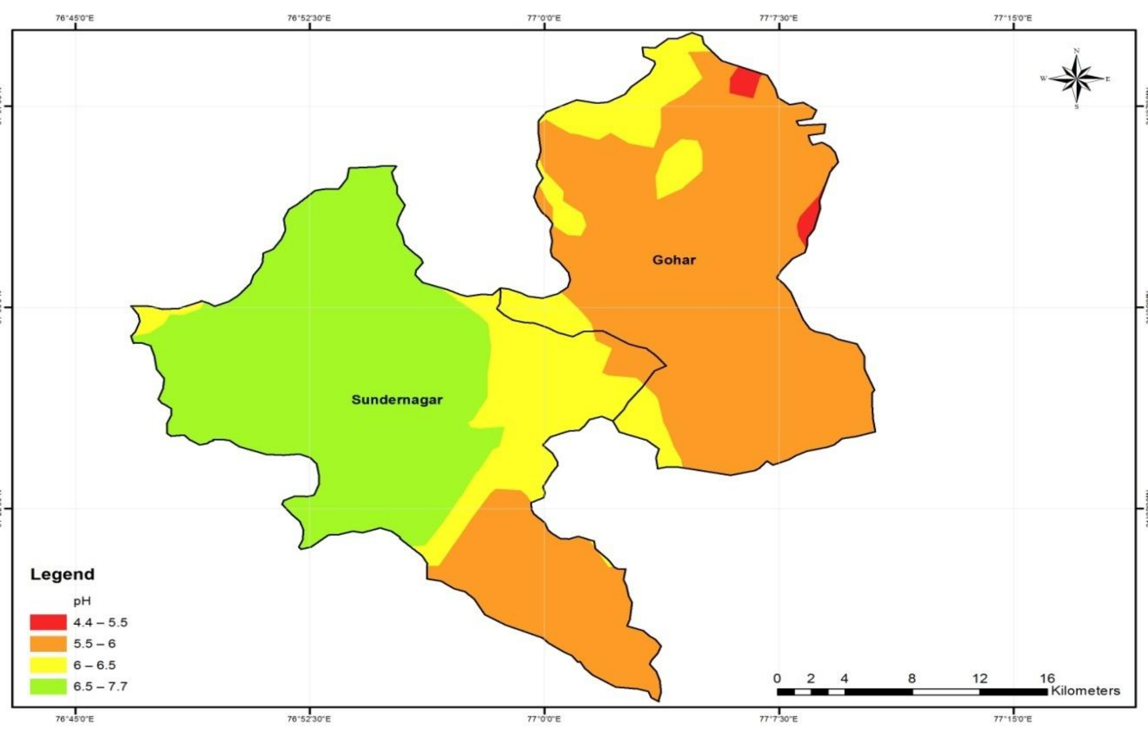

Figure 4.4 Spatial distribution map of soil pH (0-15cm)

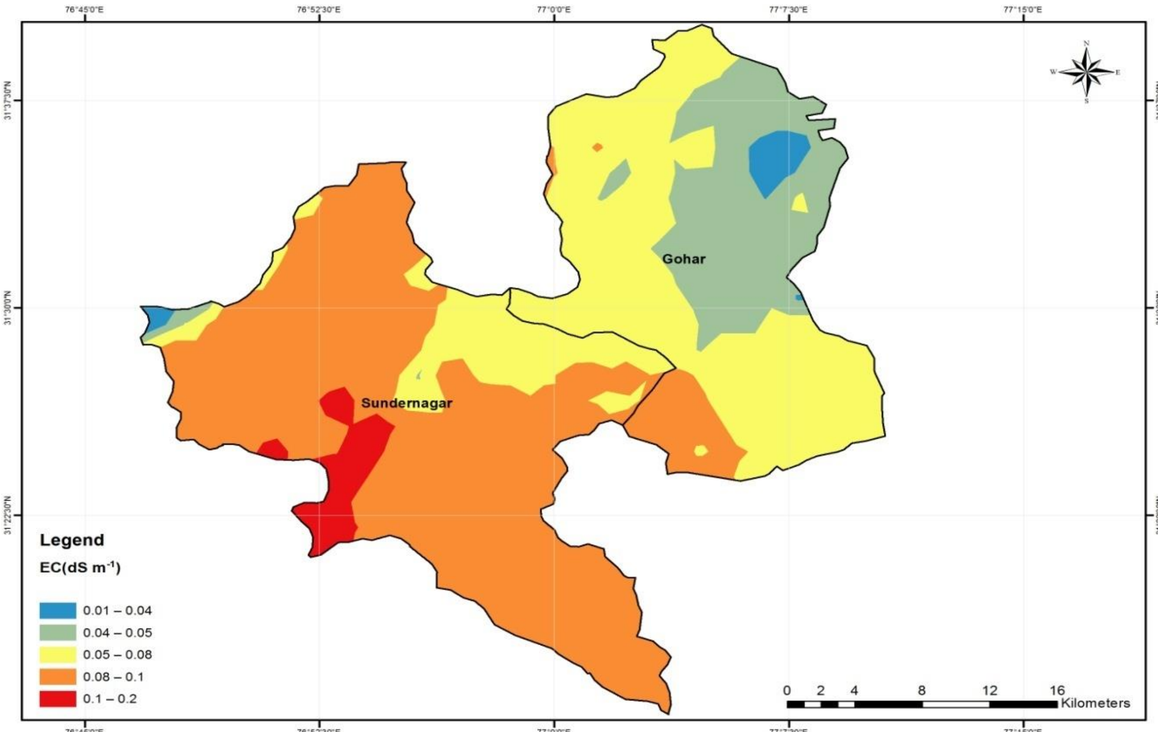

Figure 4.5 Spatial distribution map of electrical conductivity (0-15cm)

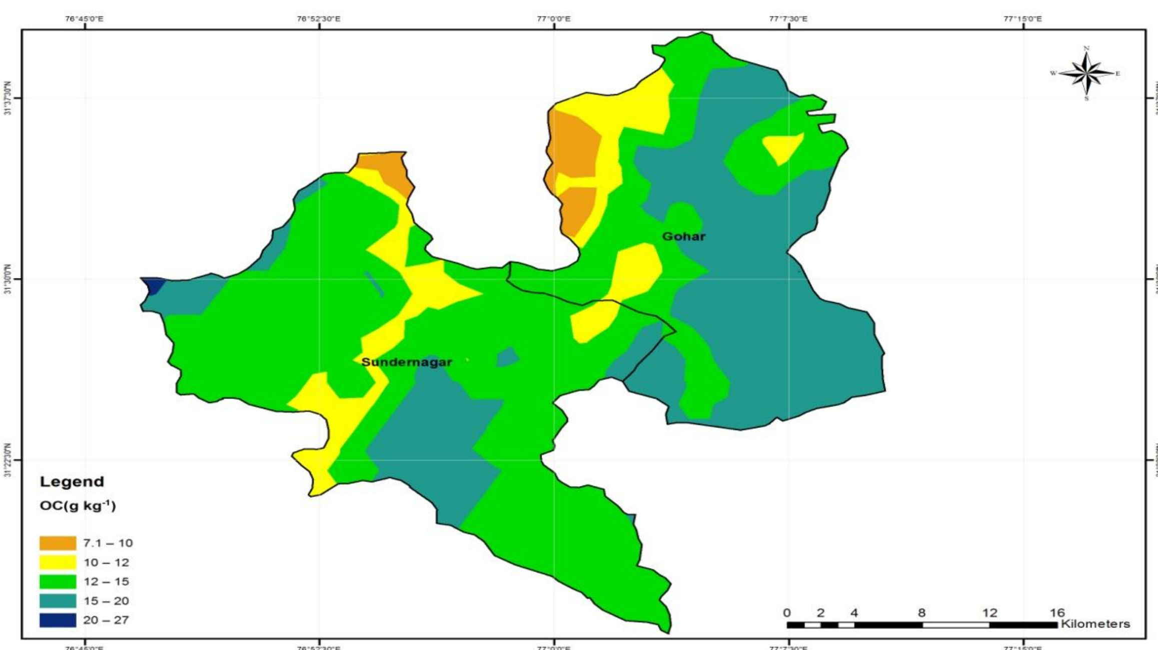

Figure 4.6 Spatial distribution map of soil organic carbon (0-15cm)

4.1.1.5 Organic carbon (OC)

Organic carbon is the key component of soils because of its influence on physical, chemical and soil biota (Table 4.3). The organic carbon content of the soils varied from 2.6 to 26.9 g kg^{-1} and 3.5 to 24.0 g kg^{-1} with mean values of 13.8 g kg^{-1} and 11.5 g kg^{-1} in surface and sub-surface soils, respectively. The organic carbon content decreased with increase in soil depth. In surface and sub-surface soils, the lowest mean organic carbon (4.5 g kg^{-1} and 4.0 g kg^{-1}) content was recorded in Chachyot village under Gohar block, whereas, highest values for respective layers were found in Bhawanipur (23.6 g kg^{-1}) village under Gohar block and Maun (23.0 g kg^{-1}) village under Sundernagar block, respectively. The data clearly indicates that the soils of vegetable growing areas of Mandi district are medium to high in organic carbon status (Table 3.4). The spatial distribution map of OC of pea growing areas is presented in Figure 4.6.

The majority of soil samples found medium and high in organic carbon status. The higher addition of FYM, low temperature, high rainfall and continuous mineralization of organic matter in surface layer may be responsible for higher values of organic carbon in surface layer as compared to sub-surface layers. These results are in line with the findings of Tripathi *et al.* (1992) who reported that organic carbon content in the soils of Mandi district ranges from 0.20 to 2.6 per cent. These results are also supported by Sharma and Kanwar (2012), Annepu *et al.* (2017) and Sharma *et al.* (2018a).

4.1.2 Macronutrient status of soil

The soils of pea growing areas of the district were analyzed for available nitrogen, phosphorus, potassium, sulphur, exchangeable calcium and magnesium and the results of the analysis are presented in Table 4.4 and 4.5.

4.1.2.1 Available nitrogen (N)

A perusal of data in the Table 4.4 reveals that the available N content in surface soils ranged from 94.1 to 345.0 kg ha^{-1} and in sub-surface samples 62.7 to 313.6 kg ha^{-1} with mean values of 168.0 kg ha^{-1} and 140.1 kg ha^{-1}, respectively. In surface and sub-surface samples, the lowest (98.2 kg ha^{-1} and 77.2 kg ha^{-1}) and highest (286.0 kg ha^{-1} and 221.1 kg ha^{-1}) mean values of available nitrogen content were recorded in Sakor village under Sundernagar block and Nalahar village under Gohar block, respectively. The available nitrogen content decreases with increase in soil depth. On classifying the data into different classes of soil fertility levels (Table 3.4), it was found that soils are low in available nitrogen. The spatial distribution map of

Table 4.4 Available nitrogen, phosphorus and potassium in vegetable growing soils of Mandi district

Sr. No.	Location	Available nitrogen ($kg\ ha^{-1}$)		Available phosphorus ($kg\ ha^{-1}$)		Available potassium ($kg\ ha^{-1}$)	
		Soil depth (cm)					
		0-15	15-30	0-15	15-30	0-15	15-30
1	Majothi	156.8-188.2 (177.4)	94.1-125.4 (111.7)	41.2-61.1 (51.1)	15.4-27.7 (20.2)	195.9-224.0 (207.8)	182.2-193.7 (186.6)
2	Bhawanipur	188.2-219.5 (209.1)	156.8-180.2 (171.7)	31.5-94.0 (68.0)	23.2-49.6 (36.7)	219.5-225.9 (222.3)	215.2-224.1 (218.5)
3	Kharsi	156.8-188.2 (168.7)	132.8-160.1 (144.4)	19.3-49.6 (35.0)	15.4-43.8 (28.5)	134.1-161.6 (148.4)	125.0-153.8 (134.3)
4	Thachi	137.5-282.2 (202.6)	108.6-219.5 (160.5)	32.8-74.7 (53.2)	20.6-34.8 (29.6)	176.2-182.0 (179.2)	135.0-154.9 (146.5)
5	Nalahar	262.1-313.6 (286.0)	188.1-281.3 (221.1)	137.1-144.2 (139.7)	108.1-121.7 (113.9)	219.0-236.7 (228.6)	162.0-179.8 (172.2)
6	Sheladhar	209.3-320.5 (249.8)	156.2-313.6 (219.3)	74.0-115.2 (90.3)	55.4-71.4 (61.8)	118.5-151.9 (133.6)	85.4-108.5 (97.7)
7	Deem	219.5-345.0 (282.2)	182.6-258.5 (220.2)	26.4-45.7 (33.5)	16.7-37.3 (25.3)	130.7-147.0 (137.8)	110.3-125.9 (117.9)
8	Bassi	157.2-250.9 (209.2)	142.9-231.0 (184.9)	39.9-47.0 (42.3)	30.3-36.7 (33.5)	493.0-523.0 (507.0)	225.8-250.1 (240.4)
9	Duga	153.2-229.6 (191.4)	125.6-193.4 (159.5)	55.4-65.0 (60.2)	9.0-20.0 (14.5)	224.0-238.8 (231.4)	175.9-186.9 (181.4)
10	Kotla	95.2-156.8 (125.8)	82.5-133.6 (107.2)	30.9-94.6 (55.8)	12.2-83.7 (39.3)	169.6-190.4 (180.7)	155.9-199.6 (172.4)
11	Bhava	96.5-161.8 (131.7)	72.4-150.8 (108.6)	58.6-97.2 (77.4)	20.6-77.2 (41.6)	489.9-550.3 (523.7)	170.6-258.9 (201.5)
12	Daan	159.4-180.1 (169.6)	141.3-163.4 (149)	109.4-173.1 (137.1)	41.2-43.8 (39.9)	606.3-740.9 (679.5)	225.2-268.7 (245.7)
13	Taneli	125.0-156.8 (135.8)	100.5-138.7 (116.9)	48.9-173.8 (120.8)	9.7-78.5 (40.8)	158.4-184.1 (170.3)	123.4-143.2 (133.3)
14	Gohar	156.1-189.2 (174.4)	118.0-171.1 (149.9)	68.2-99.8 (82.6)	45.1-75.7 (55.8)	161.9-210.2 (182.5)	115.6-158.7 (134.5)
15	Khayod	151.2-198.6 (175.5)	131.9-173.1 (149.6)	77.2-95.3 (88.6)	44.4-75.7 (57.7)	127.1-158.5 (144.2)	79.1-90.1 (94.9)
16	Dari	157.8-191.7 (176.8)	156.2-179.3 (170.7)	65.7-79.2 (74.4)	42.5-61.1 (49.1)	230.5-273.0 (251.4)	180.0-206.3 (193.7)
17	Masog	103.4-160.1 (133.4)	95.0-151.3 (123.1)	65.7-88.8 (75.9)	54.7-65.7 (61.1)	287.5-422.9 (370.4)	359.8-380.1 (368.3)
18	Chachyot	94.1-120.0 (106.1)	68.8-95.1 (84.7)	35.4-72.7 (56.2)	30.3-38.0 (33.7)	179.9-218.9 (197.4)	160.1-177.2 (169.4)
19	Bharjodu	182.3-287.2 (219.2)	149.8-223.1 (176.1)	34.8-45.7 (39.0)	22.5-26.4 (24.7)	157.3-172.9 (164.0)	133.3-152.6 (141.4)
20	Kot	115.0-145.8 (128.8)	91.6-132.6 (108.5)	95.9-126.8 (114.6)	43.1-106.9 (79.8)	512.8-705.5 (585.1)	223.6-235.8 (228.9)
21	Naugraun	211.5-250.8 (227.2)	185.6-200.5 (192.2)	38.6-137.7 (78.3)	18.7-40.6 (28.2)	186.9-212.8 (201.1)	122.3-155.5 (141.1)
22	Saloyi	199.0-221.3 (210.5)	174.6-194.1 (184.5)	34.8-74.7 (52.1)	27.0-64.4 (44.0)	450.0-557.9 (510.3)	281.5-313.8 (295.6)
23	Kutwachi	172.4-249.7 (213.4)	146.3-181.3 (162.3)	33.5-45.1 (40.5)	29.0-41.2 (35.8)	410.4-475.8 (449.0)	247.9-305.9 (273.27)
24	Kharadhar	181.3-217.0 (196.2)	143.3-186.3 (165.0)	39.9-66.3 (57.1)	34.1-61.1 (51.7)	432.8-488.3 (457.5)	221.7-312.1 (268.3)

25	Sakor	96.2-100.0 (98.2)	62.7-88.2 (77.2)	85.6-104.9 (95.4)	47.0-90.8 (65.0)	424.6-565.0 (472.0)	234.1-459.9 (315.8)
26	Sangli	123.6-158.1 (140.3)	101.9-142.6 (121.8)	31.3-144.2 (81.4)	26.4-66.9 (46.8)	203.0-692.7 (554.3)	183.6-584.4 (431.2)
27	Thamadi	95.2-159.2 (117.2)	68.3-145.6 (98.5)	15.4-38.0 (23.4)	7.7-25.7 (15.7)	232.2-405.9 (298.7)	144.1-298.2 (233.0)
28	Chuni	97.0-190.5 (136.0)	78.3-152.4 (110.8)	27.7-90.1 (62.4)	25.1-56.0 (42.5)	406.6-495.1 (442.0)	162.6-312.3 (225.1)
29	Rohanda	153.7-230.1 (191.7)	122.1-215.7 (171.8)	76.6-111.4 (95.7)	68.2-90.8 (80.0)	223.6-497.5 (379.1)	191.7-316.7 (250.4)
30	Ghasnu	215.5-248.1 (228.3)	161.5-198.5 (178.1)	90.7-115.9 (101.7)	38.0-78.5 (58.8)	333.0-382.0 (351.8)	203.4-249.2 (223.8)
31	Kamand	128.6-169.7 (146.3)	110.9-145.9 (123.4)	82.4-141.0 (104.7)	62.4-136.5 (88.4)	406.8-460.9 (438.8)	184.0-214.2 (202.6)
32	Kathel	194.9-214.6 (206.6)	167.5-176.0 (171.5)	56.0-144.8 (110.3)	45.1-119.8 (80.3)	656.8-752.9 (694.8)	337.5-383.7 (362.4)
33	Okhal	129.9-168.5 (151.0)	99.9-128.6 (118.0)	122.9-159.0 (141.0)	106.9-134.5 (119.5)	644.4-747.5 (688.0)	447.6-485.5 (466.8)
34	Majhar	196.3-224.3 (210.3)	154.7-197.8 (176.3)	130.7-135.8 (133.2)	76.0-106.2 (91.1)	317.5-359.4 (338.4)	215.2-235.4 (225.3)
35	Majhothi	151.0-169.9 (158.9)	118.7-125.6 (123.1)	168.6-171.9 (170.1)	122.3-129.4 (125.7)	235.1-267.1 (242.8)	165.6-191.2 (177.5)
36	Rohangalu	99.5-126.0 (115.0)	84.4-110.9 (94.3)	148.7-173.8 (163.1)	86.3-135.8 (116.1)	455.3-504.9 (478.6)	323.2-380.8 (355.5)
37	Laag	100.5-131.4 (116.0)	91.1-118.8 (104.9)	165.4-171.2 (168.3)	108.1-112.6 (110.4)	164.0-171.0 (167.5)	118.0-121.0 (119.5)
38	Nalni	114.0-160.5 (137.2)	98.5-156.5 (127.5)	156.4-157.1 (156.7)	134.5-142.3 (138.4)	211.9-224.4 (218.1)	152.5-159.2 (155.9)
39	Dol	149.9-219.5 (184.7)	136.9-188.1 (162.5)	97.2-129.4 (113.3)	87.5-93.3 (90.4)	746.3-830.9 (788.6)	337.4-358.1 (347.8)
40	Dharli	142.1-155.9 (149.0)	126.6-129.4 (128.0)	126.8-166.7 (146.8)	104.3-144.8 (124.5)	120.3-126.1 (123.2)	85.4-87.6 (86.5)
41	Ghurangalu	116.5-158.0 (137.2)	100.6-129.8 (115.2)	98.5-108.8 (103.6)	85.0-92.0 (88.5)	181.6-198.7 (190.2)	145.9-158.6 (152.3)
42	Jai Devi	97.8-117.9 (107.9)	85.7-101.7 (93.7)	138.4-160.9 (149.7)	86.3-111.4 (98.8)	137.7-148.7 (143.2)	110.3-112.0 (111.2)
43	Kandyah	114.8-160.4 (134.7)	99.6-132.9 (114.4)	93.3-146.8 (126.4)	72.1-126.8 (105.3)	188.7-218.9 (202.5)	146.3-159.5 (152.8)
44	Chatar	106.6-129.8 (116.3)	89.5-102.6 (96.6)	159.0-165.4 (162.0)	120.4-139.7 (129.4)	128.8-150.1 (137.6)	78.9-93.2 (83.9)
45	Rada	116.9-152.9 (131.5)	101.5-142.9 (119.1)	131.3-169.9 (155.6)	102.3-125.5 (115.6)	404.4-445.8 (429.7)	225.3-302.9 (272.4)
46	Khilra	99.5-163.3 (127.7)	72.9-144.7 (109.8)	122.3-151.9 (139.5)	92.0-126.2 (108.4)	383.0-411.0 (399.0)	314.7-338.4 (330.4)
47	Maun	167.5	136.8	95.3	61.1	176.7	166.6
48	Gullas	99.2	85.5	15.5	7.8	393.6	345.1
49	Ghiri	179.9	128.5	63.7	25.7	225.2	214.7
	Range	**94.1-345.0**	**62.7-313.6**	**15.4-173.8**	**7.7-144.8**	**118.5-830.9**	**78.9-584.4**
	Mean	**168.0**	**140.1**	**93.4**	**64.5**	**335.9**	**219.2**
	SE (±)	**4.5**	**3.8**	**4.0**	**3.3**	**15.8**	**8.7**
	CV (%)	**31.3**	**31.7**	**49.4**	**59.4**	**54.5**	**46.0**

**Values in parenthesis indicate mean*

of pea growing areas is presented in Figure 4.7.

The majority of soil samples fall in the low available nitrogen category. This may be due to reduced rate of organic matter decomposition at low temperature in the region thus, temporarily withholding the mineralization of nitrogen and continuous cultivation of peas and other vegetables which needed high nutrients. It may also be due to nutrient management practices followed by the farmers of the area and leaching losses of the nitrogen from the soil. The higher content of organic carbon in the surface layers may be responsible for higher nitrogen content in the surface layers as compared to the sub-surface layers. The results are in conformity with the findings of Raina (1988) soils of Poanta valley of Himachal Pradesh were low in available N. Dhale and Prasad (2009) for the Maharashtra soils and Loria *et al.* (2016) in the soils of Himachal Pradesh found a decreased content of different forms of available N with the increase in profile depth.

4.1.2.2 Available phosphorus (P)

The available P content of the soils ranged from 15.4 to 173.8 kg ha^{-1} and 7.7 to 144.8 kg ha^{-1} with mean values of 93.4 and 64.5 kg ha^{-1} in the surface and sub-surface soils, respectively (Table 4.4). The lowest mean available P content (15.5 kg ha^{-1} and 7.8 kg ha^{-1}) in surface and sub-surface samples were recorded in Gullas village under Sundernagar block, whereas, in surface and sub-surface samples, the highest mean available P content (170.1 kg ha^{-1} and 138.4 kg ha^{-1}) were recorded in Majhothi and Nalni villages under Sundernagar block, respectively. The available phosphorus content decreases with increase in soil depth. Available P status is high in majority of the area (Table 3.4). The spatial distribution map of available phosphorus of pea growing areas is presented in Figure 4.8.

The high availability of phosphorus in surface soils may be due to high organic matter content and use of 12-32-16 fertilizer by the farmers as a source of P in adequate quantities. The results obtained in the present investigation are supported by the findings of Sharma and Kanwar (2012) who found high levels of phosphorus in pea growing soils of Himachal Pradesh. A decrease in available phosphorus with increase in soil depth has been also reported by various workers (Loria *et al.*, 2016; Kumar and Paliyal, 2018).

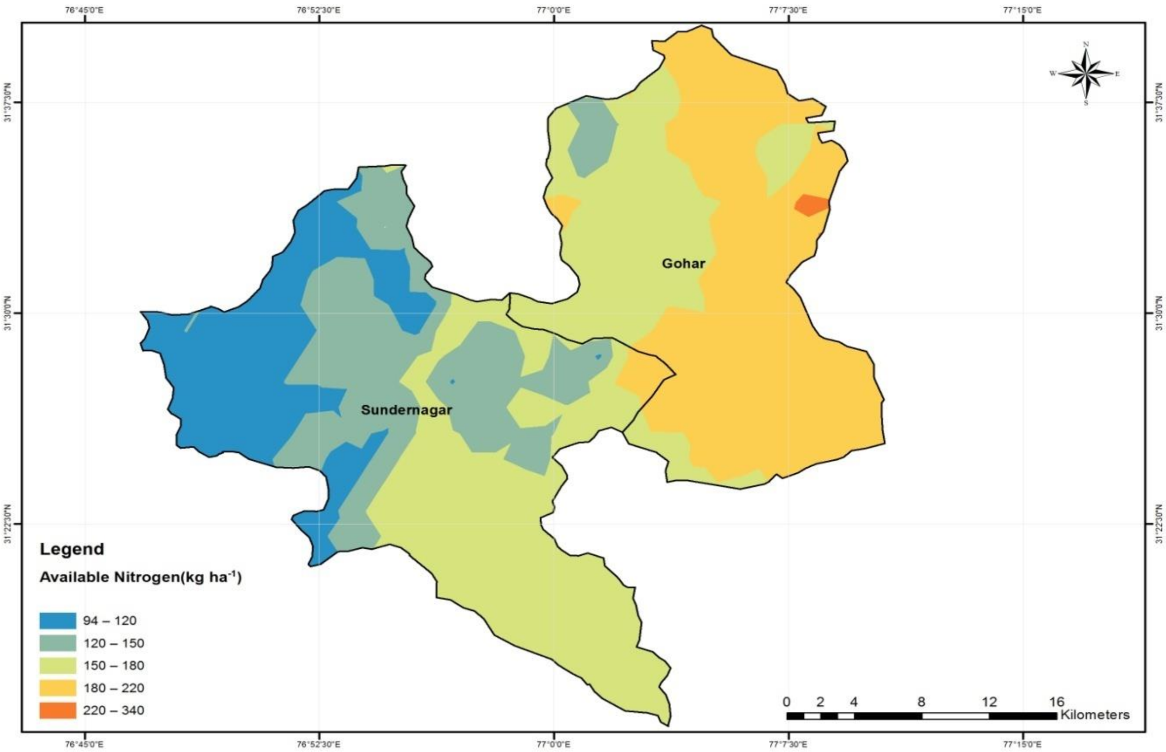

Figure 4.7 Spatial distribution map of available nitrogen (0-15cm)

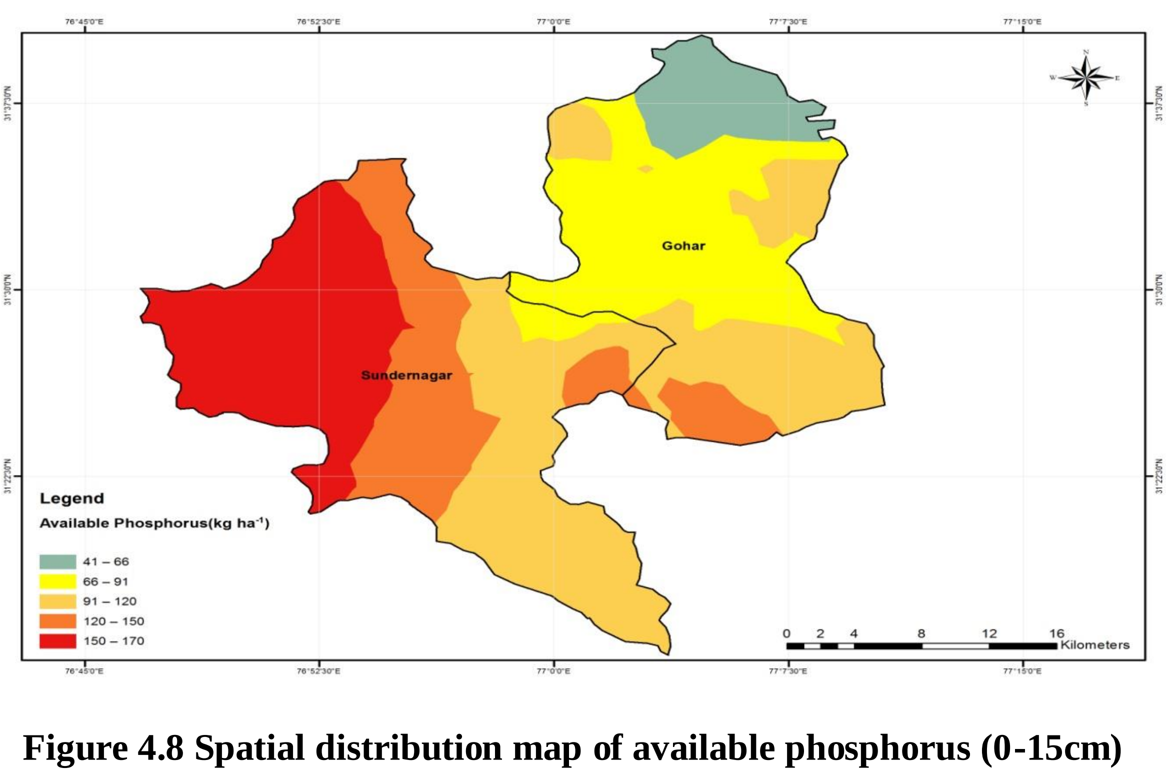

Figure 4.8 Spatial distribution map of available phosphorus (0-15cm)

4.1.2.3 Available potassium (K)

The data regarding the available potassium content in the soils of the study area is presented in Table 4.4. The data shows that in surface and sub-surface soils available K content ranged from 118.5 to 830.9 and 78.9 to 584.4 kg ha^{-1} with mean values of 335.9 kg ha^{-1} and 219.2 kg ha^{-1}, respectively. Surface (123.2 kg ha^{-1}) and sub-surface (83.9 kg ha^{-1}) soil samples of Dharli and Chatar villages under Sundernagar block recorded the lowest mean values. The highest mean values of surface (788.6 kg ha^{-1}) and sub-surface (466.8 kg ha^{-1}) samples were observed in Dol and Okhal villages under Sundernagar block, respectively. The available potassium was found to decrease with increase in soil depth. The overall available potassium is found to be medium to high status in vegetable growing soils of the district (Table 3.4). The spatial distribution map of available potassium of pea growing areas is presented in Figure 4.9.

Mahajan *et al.* (2007) and Chander *et al.* (2014) have also reported high level of potassium in many soils of the region, which they have ascribed to the nature of parent material, management practices along with the addition of manures and fertilizers in the fields. Like N and P, the distribution pattern of available K also revealed decrease in its content in the sub-surface depth. A similar trend has also been reported by Kumar and Verma (2005), Kumar *et al.* (2017b) and Singh *et al.* (2019).

4.1.2.4 Exchangeable calcium (Ca)

The exchangeable Ca content of studied soil samples ranged from 2.99 to 5.91 [cmol (p^+) kg^{-1}] and 2.07 to 5.13 [cmol (p^+) kg^{-1}] with mean values of 4.85 [cmol (p^+) kg^{-1}] and 4.01 [cmol (p^+) kg^{-1}] in surface and sub-surface soils, respectively (Table 4.5). In surface and sub-surface samples, the lowest [3.08 cmol (p^+) kg^{-1} and 2.11 cmol (p^+) kg^{-1}] and highest [5.90 cmol (p^+) kg^{-1} and 4.83 cmol (p^+) kg^{-1}] mean exchangeable Ca content were recorded in Kharsi and Kot villages under Gohar block, respectively. The exchangeable calcium content decreases with increase in soil depth. All the soils of the study area are sufficient in available Ca (Table 3.4). The spatial distribution map of exchangeable Ca of pea growing areas is presented in Figure 4.10.

The higher values of exchangeable Ca in surface soils may be attributed to the nature of parent material and use of complex fertilizers in vegetable crops in the region. Mahajan *et al.* (2007) reported that exchangeable Ca content varied between 2.07 to 5.12 [cmol (p^+) kg^{-1}] in soils of vegetable growing areas of Balh valley of Himachal Pradesh. Similarly, Chander *et al.* (2014) reported that soils of mid hills sub-humid zone of Himachal Pradesh were sufficient in exchangeable Ca. As far as depth wise distribution is concerned, Ca in general, exhibited a

Table 4.5 Exchangeable calcium (Ca), magnesium (Mg) and available sulphur in vegetable growing soils

Sr. No.	Location	Ca [Cmol (p^+) kg^{-1}]		Mg [Cmol (p^+) kg^{-1}]		Available sulphur (mg kg^{-1})	
		Soil depth (cm)					
		0-15	15-30	0-15	15-30	0-15	15-30
1	Majothi	3.50-3.69 (3.59)	2.10-2.67 (2.44)	2.11-2.35 (2.23)	1.96-3.01 (2.40)	51.9-56.9 (54.4)	34.4-45.3 (40.0)
2	Bhawanipur	3.76-3.98 (3.87)	2.75-2.97 (2.86)	2.09-2.23 (2.20)	1.84-2.30 (2.10)	48.6-50.6 (49.9)	38.6-49.7 (42.6)
3	Kharsi	2.99-3.19 (3.08)	2.07-2.18 (2.11)	2.28-2.78 (2.53)	2.21-2.69 (2.37)	12.5-51.9 (38.1)	46.7-51.1 (49.0)
4	Thachi	3.69-3.86 (3.78)	2.65-2.84 (2.75)	2.99-3.24 (3.10)	2.71-3.04 (2.92)	47.50-55.3 (51.4)	45.6-53.9 (49.1)
5	Nalahar	3.55-3.76 (3.65)	2.50-2.71 (2.63)	2.33-2.97 (2.65)	2.28-2.75 (2.53)	38.1-45.8 (41.3)	34.4-38.1 (36.0)
6	Sheladhar	3.87-4.05 (3.96)	2.83-3.01 (2.91)	3.03-3.32 (3.17)	2.99-3.30 (3.13)	38.1-54.4 (45.8)	37.2-47.2 (41.5)
7	Deem	4.01-4.19 (4.10)	3.00-3.15 (3.08)	2.25-2.89 (2.55)	2.01-2.62 (2.37)	40.8-54.4 (48.3)	39.7-48.9 (42.8)
8	Bassi	4.25-4.38 (4.32)	3.25-3.30 (3.27)	1.92-2.50 (2.25)	1.98-2.46 (2.22)	46.1-48.6 (47.3)	41.9-46.4 (44.6)
9	Duga	4.26-4.39 (4.32)	3.06-3.21 (3.13)	2.62-2.98 (3.16)	2.30-2.92 (2.61)	38.9-43.9 (41.4)	35.6-40.6 (38.1)
10	Kotla	4.25-4.46 (4.37)	3.05-3.40 (3.18)	3.12-3.89 (3.48)	2.97-3.40 (3.21)	40.8-56.4 (46.7)	29.4-48.1 (38.5)
11	Bhava	4.66-4.84 (4.74)	3.61-3.81 (3.70)	3.15-3.36 (3.26)	3.02-3.10 (3.06)	51.7-56.1 (54.3)	48.1-54.4 (51.4)
12	Daan	4.48-4.69 (4.58)	3.47-3.66 (3.56)	2.81-3.63 (3.28)	2.76-3.30 (3.06)	45.3-50.3 (48.1)	36.1-42.5 (39.2)
13	Taneli	4.76-7.95 (4.83)	3.76-3.93 (3.85)	2.58-3.74 (3.09)	2.50-3.44 (2.93)	48.9-55.3 (52.5)	35.3-50.3 (43.7)
14	Gohar	5.12-5.35 (5.24)	4.10-4.30 (4.20)	2.16-2.64 (2.43)	2.02-2.46 (2.30)	38.6-50.3 (46.0)	29.4-38.9 (33.3)
15	Khayod	5.15-5.33 (5.23)	4.21-4.51 (4.34)	2.14-2.46 (2.32)	1.94-2.26 (2.14)	34.4-56.7 (43.8)	29.4-40.0 (34.0)
16	Dari	5.23-5.45 (5.34)	4.27-4.48 (4.37)	3.03-3.12 (3.06)	2.76-2.93 (2.85)	36.4-53.9 (44.4)	33.9-51.1 (41.1)
17	Masog	5.20-5.46 (5.33)	4.22-4.38 (4.31)	2.72-3.52 (3.02)	2.58-3.35 (2.87)	46.4-57.2 (52.2)	32.2-40.8 (37.0)
18	Chachyot	5.61-5.80 (5.71)	4.63-4.75 (4.71)	2.68-3.76 (3.27)	2.20-3.56 (2.93)	36.9-49.4 (43.9)	26.4-39.4 (34.9)
19	Bharjodu	5.70-5.81 (5.75)	4.71-4.83 (4.75)	2.66-2.80 (2.74)	2.42-2.70 (2.59)	38.3-50.8 (45.9)	29.4-42.5 (34.3)
20	Kot	5.89-5.91 (5.90)	4.78-4.93 (4.83)	2.54-2.78 (2.67)	2.45-2.70 (2.61)	50.8-54.7 (53.2)	33.6-42.2 (37.4)
21	Naugraun	5.70-5.91 (5.80)	4.60-4.99 (4.82)	2.50-2.56 (2.54)	2.35-2.51 (2.43)	40.3-51.4 (46.4)	34.4-47.8 (42.6)
22	Saloyi	5.61-5.80 (5.71)	4.51-4.75 (4.63)	1.99-2.52 (2.17)	1.85-2.29 (2.03)	37.8-54.4 (46.0)	35.6-47.2 (40.3)
23	Kutwachi	5.23-5.46 (5.38)	4.17-4.48 (4.34)	2.19-2.44 (2.29)	2.02-2.38 (2.19)	38.1-49.7 (44.3)	37.2-40.0 (39.0)
24	Kharadhar	5.26-5.70 (5.43)	4.29-4.73 (4.44)	1.98-2.70 (2.42)	1.85-2.57 (2.31)	40.8-54.4 (49.8)	39.7-48.9 (45.0)

25	Sakor	5.26-5.70 (5.44)	4.35-4.74 (4.46)	2.05-2.76 (2.33)	1.72-2.59 (2.07)	13.1-18.6 (16.1)	12.2-15.8 (14.7)
26	Sangli	5.23-5.80 (5.52)	4.33-4.75 (4.53)	2.01-3.12 (2.73)	1.87-2.89 (2.50)	15.6-20.3 (18.1)	13.3-15.6 (14.3)
27	Thamadi	5.71-5.90 (5.81)	4.68-4.88 (4.79)	2.02-3.32 (2.69)	1.78-3.06 (2.51)	17.8-18.1 (17.9)	10.0-16.4 (13.8)
28	Chuni	4.86-5.20 (5.00)	3.8-4.85 (4.15)	2.22-3.32 (2.77)	2.16-3.28 (2.73)	9.7-42.2 (20.9)	8.3-37.8 (18.5)
29	Rohanda	4.56-4.95 (4.78)	4.36-4.66 (4.50)	2.70-3.19 (2.99)	2.53-3.11 (2.87)	10.0-49.4 (23.6)	8.1-39.2 (19.1)
30	Ghasnu	4.49-4.94 (4.75)	4.25-4.81 (4.48)	2.62-3.52 (3.06)	2.60-3.36 (2.93)	10.6-11.4 (10.8)	8.3-11.4 (9.3)
31	Kamand	4.42-4.81 (4.58)	3.99-4.80 (4.37)	2.53-2.90 (2.71)	2.45-2.87 (2.64)	8.3-13.1 (10.8)	8.1-9.2 (8.4)
32	Kathel	4.60-5.05 (4.83)	3.85-4.80 (4.27)	2.58-3.48 (3.12)	2.50-3.44 (3.02)	40.8-55.8 (50.5)	35.6-43.3 (38.7)
33	Okhal	4.58-5.15 (4.84)	3.89-4.76 (4.22)	2.31-3.64 (2.97)	2.25-3.60 (2.92)	8.9-53.1 (24.0)	8.1-47.8 (21.4)
34	Majhar	4.63-5.30 (4.96)	3.80-5.05 (4.42)	2.26-3.64 (2.95)	2.09-3.51 (2.80)	43.6-51.9 (47.8)	35.8-44.2 (40.0)
35	Majhothi	4.41-5.01 (4.69)	3.89-4.50 (4.15)	2.96-3.31 (3.19)	2.90-3.29 (3.12)	10.3-57.5 (39.5)	9.7-36.4 (27.2)
36	Rohangalu	4.38-4.96 (4.64)	3.75-4.28 (4.04)	2.61-3.39 (2.95)	2.58-3.28 (2.87)	50.6-55.3 (53.1)	36.1-49.4 (40.9)
37	Laag	4.40-4.88 (4.64)	3.88-4.72 (4.30)	2.58-2.85 (2.71)	2.35-2.78 (2.56)	48.9-56.4 (52.6)	36.1-36.9 (36.5)
38	Nalni	4.39-4.81 (4.60)	3.81-4.01 (3.91)	2.79-3.27 (3.03)	2.71-3.08 (2.89)	43.6-52.8 (48.2)	35.0-41.7 (38.3)
39	Dol	4.51-4.74 (4.62)	3.99-4.14 (4.07)	2.54-3.08 (2.81)	2.23-3.01 (2.62)	48.6-49.7 (49.2)	36.7-43.6 (40.1)
40	Dharli	4.47-4.69 (4.58)	3.98-4.09 (4.04)	3.01-3.09 (3.05)	2.76-2.93 (2.85)	40.6-55.0 (47.8)	34.4-40.0 (37.2)
41	Ghurangalu	4.55-4.93 (4.74)	3.90-4.03 (3.97)	2.41-2.75 (2.58)	2.26-2.64 (2.45)	46.1-56.4 (51.3)	36.4-43.3 (39.9)
42	Jai Devi	4.59-4.63 (4.61)	4.13-4.41 (4.27)	2.41-2.68 (2.55)	2.23-2.53 (2.38)	51.4-51.9 (51.7)	36.7-50.8 (43.8)
43	Kandyah	4.81-5.15 (4.98)	4.01-4.90 (4.47)	2.55-3.03 (2.81)	2.46-2.99 (2.75)	42.5-52.5 (48.5)	35.6-49.4 (40.4)
44	Chatar	4.77-5.10 (4.92)	3.96-5.00 (4.53)	2.07-2.54 (2.34)	1.93-2.45 (2.17)	40.3-55.8 (48.9)	36.4-51.1 (45.1)
45	Rada	4.40-4.99 (4.68)	3.52-4.33 (4.01)	2.23-2.57 (2.44)	2.00-2.51 (2.32)	46.7-55.0 (50.0)	36.1-46.9 (41.1)
46	Khilra	4.84-5.31 (5.03)	3.88-5.13 (4.34)	2.56-2.84 (2.65)	2.35-2.56 (2.42)	46.9-52.8 (49.4)	40.6-43.4 (42.2)
47	Maun	5.73	4.61	2.75	2.73	15.3	11.9
48	Gullas	5.51	4.50	2.92	2.89	11.7	9.4
49	Ghiri	4.99	4.10	3.03	3.01	8.6	7.8
	Range	**2.99-5.91**	**2.07-5.13**	**1.92-3.89**	**1.72-3.60**	**8.3-57.5**	**7.8-54.4**
	Mean	**4.85**	**4.01**	**2.76**	**2.62**	**41.3**	**34.7**
	SE (±)	**0.06**	**0.06**	**0.04**	**0.04**	**1.3**	**1.1**
	CV (%)	**13.76**	**18.21**	**15.97**	**16.66**	**37.15**	**37.70**

**Values in parenthesis indicate mean*

decreasing trend with increase in soil depth. Sharma *et al.* (2018a) also reported similar trend of distribution in Kangra district of Himachal Pradesh.

4.1.2.5 Exchangeable magnesium (Mg)

The data enumerated in Table 4.5 indicates that exchangeable Mg ranged from 1.92 to 3.89 [cmol (p^+) kg^{-1}] and 1.72 to 3.60 [cmol (p^+) kg^{-1}] with mean values of 2.76 and 2.62 [cmol (p^+) kg^{-1}] in surface and sub-surface soils, respectively. In surface and sub-surface samples, the lowest [2.17 cmol (p^+) kg^{-1} and 2.03 cmol (p^+) kg^{-1}] and highest [3.48 cmol (p^+) kg^{-1} and 3.21 cmol (p^+) kg^{-1}] mean exchangeable Mg content were recorded in Saloyi and Kotla villages under Gohar block, respectively. The exchangeable Mg content decreased with an increase in soil depth. All the pea growing soils in the region were sufficiently supplied with magnesium (Table 3.4). The spatial distribution map of exchangeable Mg of pea growing areas is presented in Figure 4.11.

Higher values of exchangeable Mg in surface depth may be due to high content of organic carbon and calcium carbonate. Further, higher values may also be attributed to the nutrient management practices followed by the farmers of the area and also due to the parent material. Kaistha and Gupta (1993) reported comparable values of exchangeable magnesium in the soils of Himachal Pradesh [0.1 to 4.2 cmol (p^+) kg^{-1}]. Shekhar (2009) and Kumar *et al.* (2017b) observed a decreasing trend of exchangeable Mg with the increase in the soil depth.

4.1.2.6 Available sulphur (S)

The available sulphur content of the vegetable growing soils ranged from 8.3 to 57.5 mg kg^{-1} and 7.8 to 54.4 mg kg^{-1} with mean values of 41.3 mg kg^{-1} and 34.7 mg kg^{-1} in surface and sub-surface soils, respectively (Table 4.5). Surface and sub-surface soil samples of Ghiri (8.6 mg kg^{-1} and 7.8 mg kg^{-1}) village under Sundernagar block recorded the lowest mean values for available S. Whereas, the highest mean values for surface (54.4 mg kg^{-1}) and sub-surface (51.4 mg kg^{-1}) soil samples were observed in Majothi and Bhava villages under Gohar block. Available S decreased with increase in soil depth. By comparing the value with Table 3.4, it can be inferred that soils of district are sufficient in available sulphur. The spatial distribution map of available sulphur of pea growing areas is presented in Figure 4.12.

The higher content of sulphur in the soils may be due to the presence of gypsiferrous minerals and ferruginous nature of parent material in the region (Wadia, 1966). Tripathi and Singh (1992) ascribed high sulphur content to the organic carbon which shows a highly

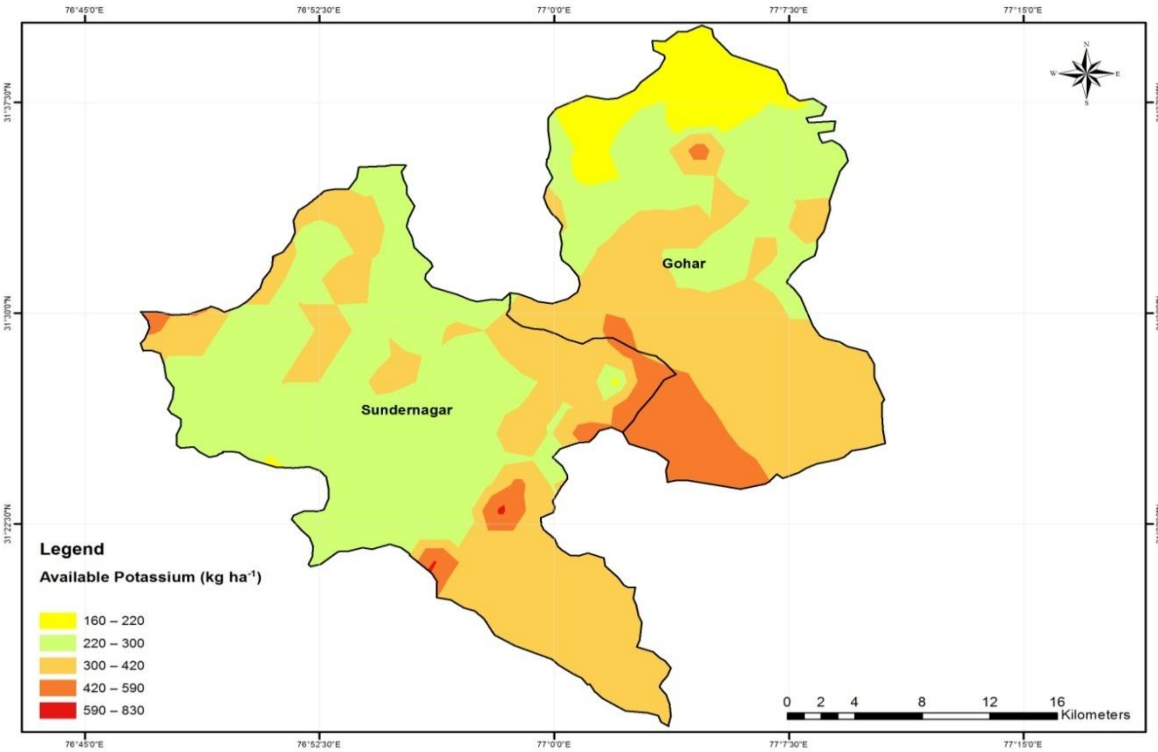

Fig. 4.9 Spatial distribution map of available potassium (0-15cm)

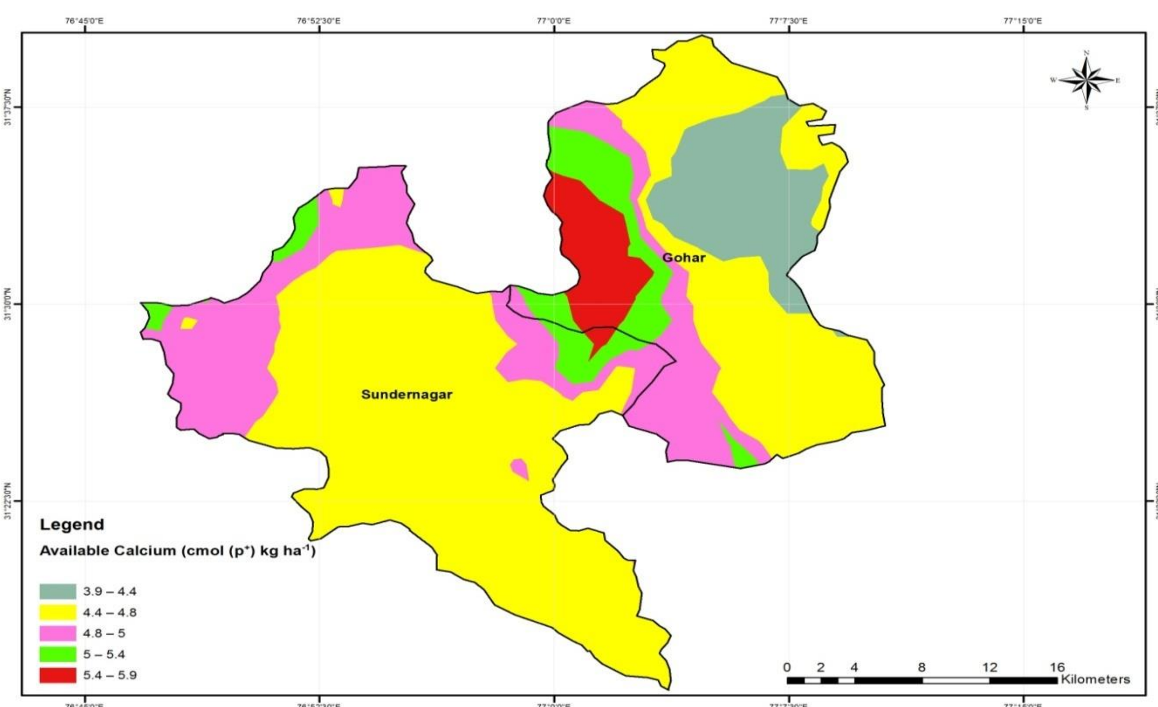

Figure 4.10 Spatial distribution map of available calcium (0-15cm)

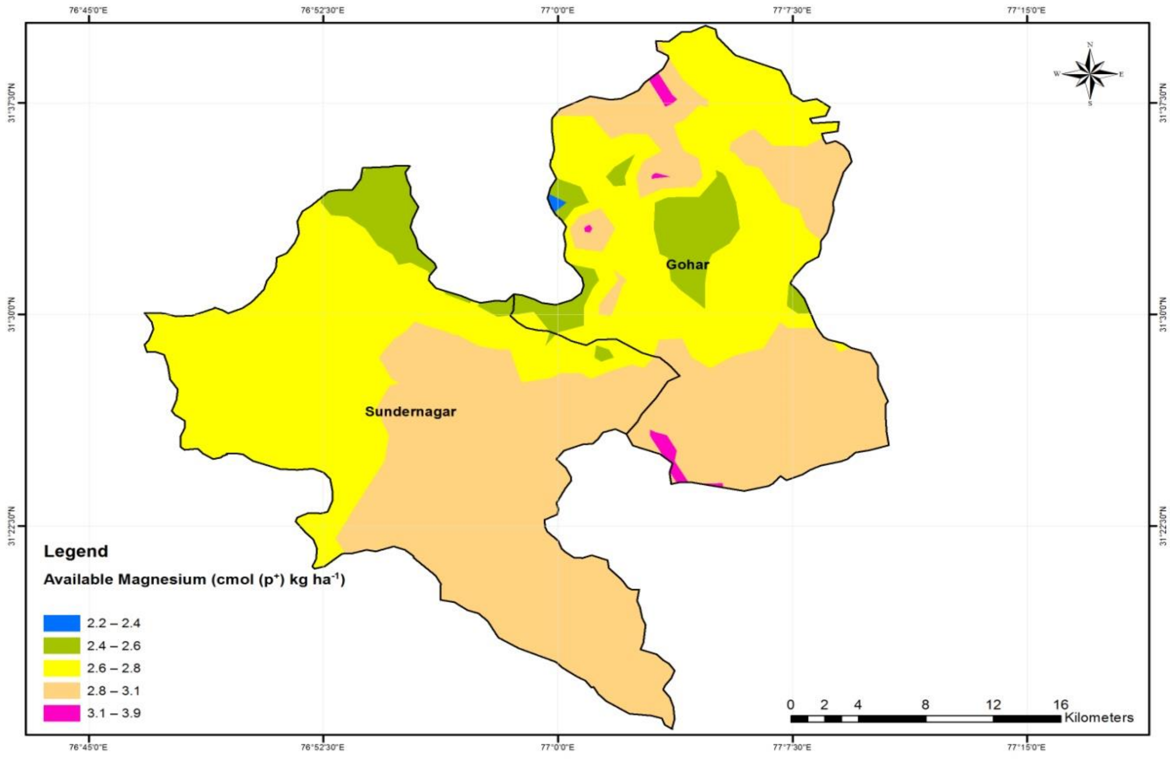

Figure 4.11 Spatial distribution map of available magnesium (0-15cm)

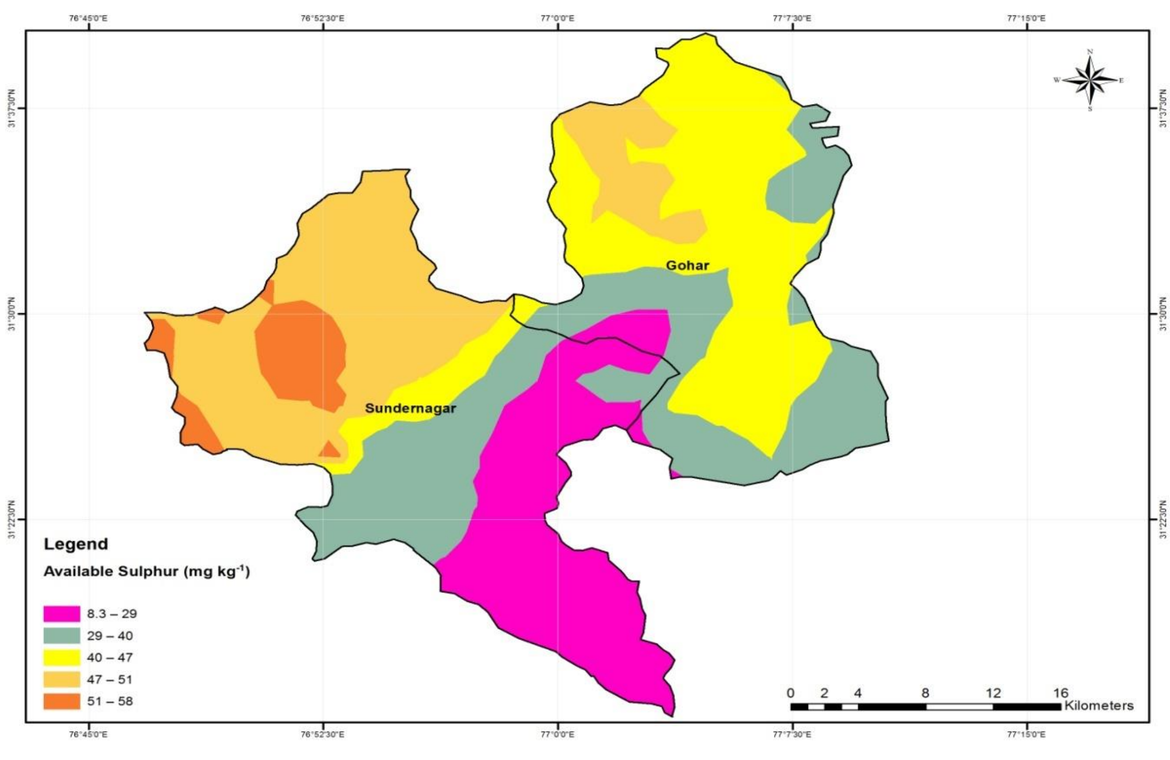

Figure 4.12 Spatial distribution map of available sulphur (0-15cm)

significant correlation in the soils of Himachal Pradesh. Further, high organic matter content and use of fertilizers like SSP may be contributing to the higher S supplies in the surface soils. The results are in accordance with the findings of Kumar and Paliyal (2016) and Sharma *et al.* (2018a).

4.1.3 Micronutrients status of soil

The soils of pea growing areas of the district were analyzed for DTPA-extractable Fe, Mn, Cu and Zn and the results of the analysis are presented in Table 4.6.

4.1.3.1 DTPA-extractable iron (Fe)

The data on the DTPA-extractable iron content of the pea growing soils is presented in Table 4.6. The DTPA-extractable Fe content ranged from 13.3 to 119.9 mg kg^{-1} and 10.7 to 117.6 mg kg^{-1} with mean values of 76.6 mg kg^{-1} and 71.9 mg kg^{-1} in surface and sub-surface soils, respectively. The lowest (32.9 mg kg^{-1} and 28.6 mg kg^{-1}) and highest (113.4 mg kg^{-1} and 109.9 mg kg^{-1}) mean DTPA-extractable Fe content in surface and sub-surface samples were recorded in Okhal village under Sundernagar block and Deem village under Gohar block, respectively. The DTPA-extractable iron was found to decrease with soil depth. The overall rating of available Fe in pea growing soils is high (Table 3.5). The spatial distribution map of DTPA-extractable iron of pea growing areas is presented in Figure 4.13.

The higher Fe content may be attributed to acidic to near neutral soil reaction beside presence of gypsiferrous and ferruginous parent materials containing hematite and limonite minerals (Wadia, 1966). The surface soils registered high available Fe content as compared to the sub-surface soils probably due to the high organic matter content in the surface soils. The results are in conformity with those of Mahajan *et al.* (2007), Chander *et al.* (2014) and Kakar *et al.* (2018b). Lahiri and Chakravarti (1989) also inferred that a high altitude soil has high availability of iron and organic matter content than the low altitude soils.

4.1.3.2 DTPA-extractable manganese (Mn)

The DTPA-extractable Mn content of the studied soil samples ranged from 2.8 to 41.2 mg kg^{-1} and 2.1 to 38.2 mg kg^{-1} with mean values of 32.3 mg kg^{-1} and 29.2 mg kg^{-1} in surface and sub-surface soils, respectively (Table 4.6). In surface and sub-surface soil samples, the lowest mean values were recorded in Kathel (7.3 mg kg^{-1} and 6.2 mg kg^{-1}) village under Sundernagar block, respectively. Whereas, highest mean values of 40.8 mg kg^{-1} and 37.0 mg kg^{-1}

Table 4.6 DTPA-extractable iron, manganese, copper and zinc in vegetable growing areas

Sr. No.	Location	Fe (mg kg^{-1})		Mn (mg kg^{-1})		Cu(mg kg^{-1})		Zn (mg kg^{-1})	
		Soil depth (cm)							
		0-15	15-30	0-15	15-30	0-15	15-30	0-15	15-30
1	Majothi	96.5-109.0 (103.4)	95.2-104.4 (99.4)	36.1-37.4 (36.6)	32.8-35.9 (34.8)	1.08-1.65 (1.39)	0.91-1.56 (1.18)	2.57-2.74 (2.64)	2.36-2.52 (2.43)
2	Bhawanipur	98.6-105.7 (103.2)	82.2-102.4 (95.3)	36.4-37.2 (36.8)	34.5-36.0 (35.4)	0.13-0.65 (0.35)	0.16-0.59 (0.31)	3.26-4.12 (3.8)	3.03-3.82 (3.54)
3	Kharsi	81.4-95.0 (89.6)	76.3-92.5 (86.5)	37.2-38.5 (37.8)	35.9-36.2 (36.1)	0.32-0.87 (0.59)	0.23-0.66 (0.46)	2.37-3.09 (2.75)	2.02-2.88 (2.45)
4	Thachi	79.9-106.6 (91.1)	77.5-104.8 (89.0)	36.4-38.1 (37.4)	35.4-37.0 (36.0)	0.32-1.48 (0.88)	0.22-1.37 (0.77)	0.04-3.10 (1.60)	0.03-2.91 (1.49)
5	Nalahar	106.0-114.6 (110.9)	102.1-110.8 (107.5)	35.3-36.8 (35.9)	32.8-35.2 (33.9)	0.54-0.65 (0.57)	0.40-0.80 (0.55)	2.57-2.99 (2.84)	2.38-2.52 (2.47)
6	Sheladhar	102.5-109.9 (107.2)	100.7-106.7 (104.4)	35.3-36.2 (35.6)	33.8-35.2 (34.3)	0.54-0.80 (0.69)	0.44-0.64 (0.56)	1.34-2.20 (1.72)	1.12-2.02 (1.53)
7	Deem	111.0-115.5 (113.4)	106.5-112.2 (109.9)	36.5-37.0 (36.8)	30.4-32.5 (31.3)	0.99-1.03 (1.01)	0.82-0.90 (0.85)	1.11-2.47 (1.82)	0.89-2.23 (1.62)
8	Bassi	83.2-89.1 (86.2)	74.1-85.2 (81.0)	36.8-37.4 (37.4)	32.7-36.1 (34.8)	2.55-2.76 (2.62)	2.21-2.52 (2.36)	2.03-2.57 (2.22)	1.86-2.31 (2.02)
9	Duga	85.0-110.2 (97.6)	80.0-101.3 (90.6)	37.6-37.9 (37.8)	31.4-35.3 (33.4)	0.49-1.10 (0.79)	0.38-0.96 (0.67)	1.83-2.37 (2.10)	1.50-1.98 (1.74)
10	Kotla	80.5-99.2 (91.8)	75.6-94.1 (87.0)	36.8-37.6 (37.1)	32.6-36.1 (34.8)	0.44-1.96 (1.10)	0.40-1.74 (0.95)	1.80-2.82 (2.24)	1.69-2.40 (1.98)
11	Bhava	86.7-100.4 (95.2)	84.9-97.9 (92.3)	36.9-37.4 (37.1)	34.5-35.9 (35.1)	0.42-1.53 (0.90)	0.32-1.35 (0.71)	1.48-4.47 (3.11)	1.37-3.99 (2.81)
12	Daan	87.3-101.6 (94.9)	83.4-93.8 (88.6)	37.2-37.9 (37.6)	33.4-36.2 (35.1)	0.51-0.73 (0.63)	0.41-0.60 (0.52)	0.55-3.31 (2.37)	0.27-3.18 (2.19)
13	Taneli	92.7-99.8 (97.2)	86.6-96.4 (92.9)	36.8-38.1 (37.5)	20.8-36.9 (29.8)	1.27-2.05 (1.59)	0.91-1.35 (1.15)	0.94-3.16 (2.03)	0.75-2.95 (1.85)
14	Gohar	101.9-119.9 (109.9)	92.8-117.6 (104.2)	36.0-36.6 (36.4)	33.8-35.3 (34.5)	2.64-3.47 (2.92)	2.24-3.10 (2.62)	3.09-7.05 (5.19)	2.73-5.85 (4.30)
15	Khayod	85.6-107.8 (97.9)	80.0-101.6 (92.5)	37.2-38.4 (37.9)	35.0-37.8 (36.4)	0.89-1.39 (1.19)	0.80-1.16 (1.02)	0.79-1.13 (0.96)	0.62-0.77 (0.72)
16	Dari	107.5-109.6 (108.5)	102.9-108.0 (105.9)	32.7-33.5 (33.1)	27.0-32.1 (30.2)	1.96-2.34 (2.17)	1.64-2.21 (1.93)	0.45-0.99 (0.77)	0.40-0.82 (0.61)
17	Masog	50.9-63.6 (55.5)	45.1-57.2 (50.9)	37.9-38.4 (38.2)	32.9-37.6 (35.0)	1.82-2.12 (1.91)	1.53-1.79 (1.66)	1.78-2.40 (2.14)	1.52-2.11 (1.91)

18	Chachyot	64.8-83.2 (74.3)	60.2-78.1 (69.2)	37.9-38.7 (38.3)	31.7-37.2 (34.9)	2.08-2.64 (2.44)	1.72-2.29 (2.08)	0.70-1.93 (1.34)	0.56-1.72 (1.13)
19	Bharjodu	96.8-103.9 (99.9)	90.3-95.3 (93.6)	37.6-38.3 (38.0)	32.2-36.3 (34.9)	0.54-1.27 (0.83)	0.40-1.07 (0.65)	1.63-2.52 (2.06)	1.56-2.20 (1.86)
20	Kot	21.0-62.7 (48.8)	17.7-57.4 (42.0)	38.4-39.1 (38.8)	31.3-38.2 (35.4)	1.67-2.12 (1.83)	1.46-1.83 (1.64)	4.15-4.69 (4.35)	3.14-4.13 (3.64)
21	Naugraun	64.5-110.7 (84.7)	59.2-103.4 (79.5)	22.6-30.6 (27.6)	22.0-27.0 (24.3)	0.56-1.06 (0.87)	0.42-0.87 (0.71)	1.56-2.17 (1.80)	1.38-1.80 (1.57)
22	Saloyi	51.5-71.6 (62.7)	49.1-67.1 (58.3)	20.7-22.3 (21.3)	16.8-19.7 (18.2)	0.49-0.92 (0.68)	0.42-0.78 (0.58)	0.57-1.36 (0.96)	0.42-1.04 (0.74)
23	Kutwachi	77.9-82.6 (80.0)	67.8-76.4 (72.2)	8.2-38.6 (28.3)	7.6-37.3 (25.5)	1.37-1.39 (1.38)	1.14-1.18 (1.16)	3.02-4.47 (3.78)	2.43-3.87 (3.26)
24	Kharadhar	58.6-72.2 (67.5)	54.1-65.2 (60.8)	23.3-29.5 (27.0)	20.9-27.9 (24.4)	0.39-0.63 (0.52)	0.31-0.54 (0.40)	2.42-2.79 (2.61)	2.18-2.42 (2.34)
25	Sakor	42.9-100.4 (73.4)	38.3-93.8 (68.6)	29.1-36.3 (33.1)	26.2-31.5 (28.4)	0.75-2.36 (1.50)	0.51-2.10 (1.31)	0.57-1.34 (0.98)	0.40-1.13 (0.71)
26	Sangli	33.4-81.4 (61.0)	27.6-78.1 (55.2)	10.6-32.6 (25.3)	9.7-30.1 (23.1)	0.61-1.67 (1.21)	0.54-1.60 (1.06)	0.99-3.26 (2.17)	0.78-2.83 (1.85)
27	Thamadi	55.6-74.6 (56.3)	35.9-67.4 (51.6)	13.7-35.2 (25.0)	9.6-30.3 (21.1)	0.42-1.39 (0.89)	0.33-1.19 (0.78)	0.49-1.09 (0.78)	0.41-0.98 (0.66)
28	Chuni	78.7-87.6 (81.7)	72.2-84.8 (77.2)	36.0-40.1 (38.1)	30.7-37.7 (33.9)	2.15-2.31 (2.21)	1.80-1.99 (1.89)	1.61-3.48 (2.43)	1.54-3.34 (2.26)
29	Rohanda	88.5-109.6 (100.0)	83.2-100.4 (92.8)	29.9-39.4 (35.9)	25.2-37.9 (32.3)	1.32-1.46 (1.40)	1.16-1.27 (1.22)	2.00-3.58 (2.74)	1.79-3.04 (2.28)
30	Ghasnu	26.9-75.8 (52.6)	24.7-70.0 (48.70)	9.4-23.7 (16.7)	8.0-19.2 (14.1)	0.49-1.27 (0.98)	0.38-1.15 (0.88)	0.52-2.42 (1.36)	0.41-1.86 (1.10)
31	Kamand	28.1-50.4 (40.4)	26.8-47.8 (38.3)	10.9-24.8 (20.1)	9.2-22.1 (17.5)	0.84-1.01 (0.89)	0.65-0.81 (0.73)	1.48-3.09 (2.06)	1.30-2.46 (1.76)
32	Kathel	13.3-63.6 (44.0)	10.7-60.4 (41.2)	2.8-11.7 (7.3)	2.1-10.2 (6.2)	0.06-0.66 (0.42)	0.10-0.57 (0.32)	0.99-2.96 (1.95)	0.30-1.77 (0.95)
33	Okhal	24.5-45.9 (32.9)	23.2-38.8 (28.6)	13.8-32.6 (21.4)	11.7-28.5 (18.3)	0.70-0.96 (0.86)	0.57-0.79 (0.71)	1.73-2.45 (2.16)	1.54-2.30 (1.86)
34	Majhar	23.0-47.9 (35.5)	18.3-41.3 (29.8)	7.3-23.3 (15.3)	6.1-21.4 (13.8)	0.18-0.42 (0.30)	0.18-0.36 (0.27)	0.50-1.83 (1.16)	0.36-1.44 (0.90)
35	Majhothi	75.2-114.0 (90.1)	70.1-110.2 (85.2)	21.7-38.9 (32.8)	19.0-35.4 (28.8)	1.96-2.83 (2.25)	1.64-2.58 (1.96)	1.51-3.60 (2.46)	1.31-3.13 (2.20)
36	Rohangalu	19.8-48.5 (33.2)	18.0-47.2 (31.2)	8.7-21.6 (17.2)	8.1-19.7 (15.3)	0.58-0.70 (0.62)	0.38-0.51 (0.44)	0.05-0.97 (0.57)	0.04-0.74 (0.45)
37	Laag	27.2-45.0	24.7-41.7	38.4-41.2	36.1-36.8	1.84-2.08	1.64-1.80	2.17-2.49	1.80-2.19

		(36.1)	(33.2)	(39.8)	(36.5)	(1.96)	(1.72)	(2.33)	(1.99)
38	Nalni	46.7-59.4 (53.1)	39.5-55.8 (47.7)	40.5-41.1 (40.8)	34.4-35.4 (34.9)	2.11-2.57 (2.34)	1.92-2.27 (2.10)	2.20-4.76 (3.48)	1.81-3.98 (2.90)
39	Dol	77.3-81.1 (79.2)	73.7-75.3 (74.5)	38.4-38.7 (38.6)	36.7-37.3 (37.0)	1.35-1.53 (1.44)	1.15-1.34 (1.25)	1.45-1.56 (1.50)	1.14-1.36 (1.25)
40	Dharli	63.3-65.4 (64.4)	57.6-62.5 (60.1)	40.3-41.1 (40.7)	35.0-37.0 (36.0)	1.51-2.19 (1.85)	1.36-1.85 (1.61)	1.56-2.25 (1.90)	1.38-1.99 (1.69)
41	Ghurangalu	66.3-69.9 (68.1)	63.1-63.3 (63.2)	29.8-30.9 (30.4)	26.1-27.1 (26.6)	1.72-4.85 (3.28)	1.52-4.10 (2.81)	0.75-5.18 (2.96)	0.42-4.04 (2.23)
42	Jai Devi	27.2-44.7 (35.9)	24.8-42.5 (33.7)	21.5-36.4 (29.0)	17.1-30.0 (23.5)	0.92-1.10 (1.01)	0.79-1.02 (0.91)	0.38-0.75 (0.56)	0.23-0.63 (0.43)
43	Kandyah	63.9-69.0 (66.5)	59.0-62.6 (60.8)	15.9-39.7 (30.7)	12.6-32.8 (25.4)	2.17-4.16 (3.28)	2.02-3.76 (2.97)	0.06-1.29 (0.72)	0.17-1.13 (0.69)
44	Chatar	61.6-75.2 (70.3)	55.2-73.4 (66.1)	38.9-40.1 (39.5)	34.8-36.2 (35.4)	3.31-4.18 (3.76)	3.13-3.97 (3.55)	0.75-1.29 (1.04)	0.62-0.98 (0.85)
45	Rada	35.5-77.6 (60.0)	31.4-73.7 (56.7)	36.5-40.9 (39.1)	33.4-34.7 (33.9)	1.81-3.00 (2.21)	1.71-2.85 (2.11)	4.76-5.01 (4.77)	3.74-4.36 (4.08)
46	Khilra	66.6-76.7 (72.3)	62.4-71.4 (68.2)	34.3-39.9 (37.4)	32.0-35.6 (33.7)	1.29-1.41 (1.34)	1.18-1.31 (1.23)	0.06-1.88 (1.01)	0.06-1.64 (0.88)
47	Maun	94.2	89.5	34.4	33.8	0.80	0.72	3.14	2.68
48	Gullas	39.8	31.8	9.4	8.1	0.44	0.37	0.33	0.22
49	Ghiri	106.0	98.8	34.2	30.0	2.31	1.91	1.98	1.58
	Range	**13.3-119.9**	**10.7-117.6**	**2.8-41.2**	**2.1-38.2**	**0.06-4.85**	**0.10-4.10**	**0.04-7.05**	**0.03-5.85**
	Mean	**76.6**	**71.9**	**32.3**	**29.2**	**1.42**	**1.23**	**2.13**	**1.83**
	SE (±)	**2.2**	**2.2**	**0.8**	**0.8**	**0.08**	**0.07**	**0.11**	**0.10**
	CV (%)	**34.0**	**35.8**	**28.4**	**30.3**	**64.36**	**68.03**	**60.07**	**61.91**

**Values in parenthesis indicate mean*

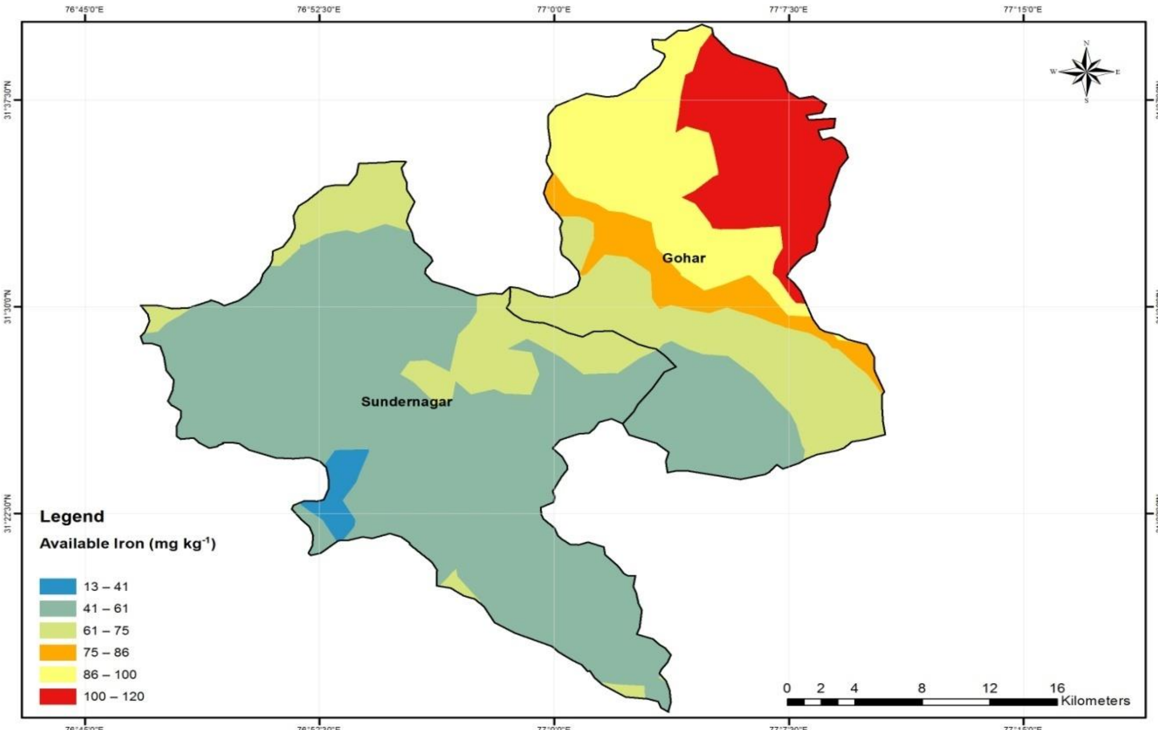

Figure 4.13 Spatial distribution map of available iron (0-15cm)

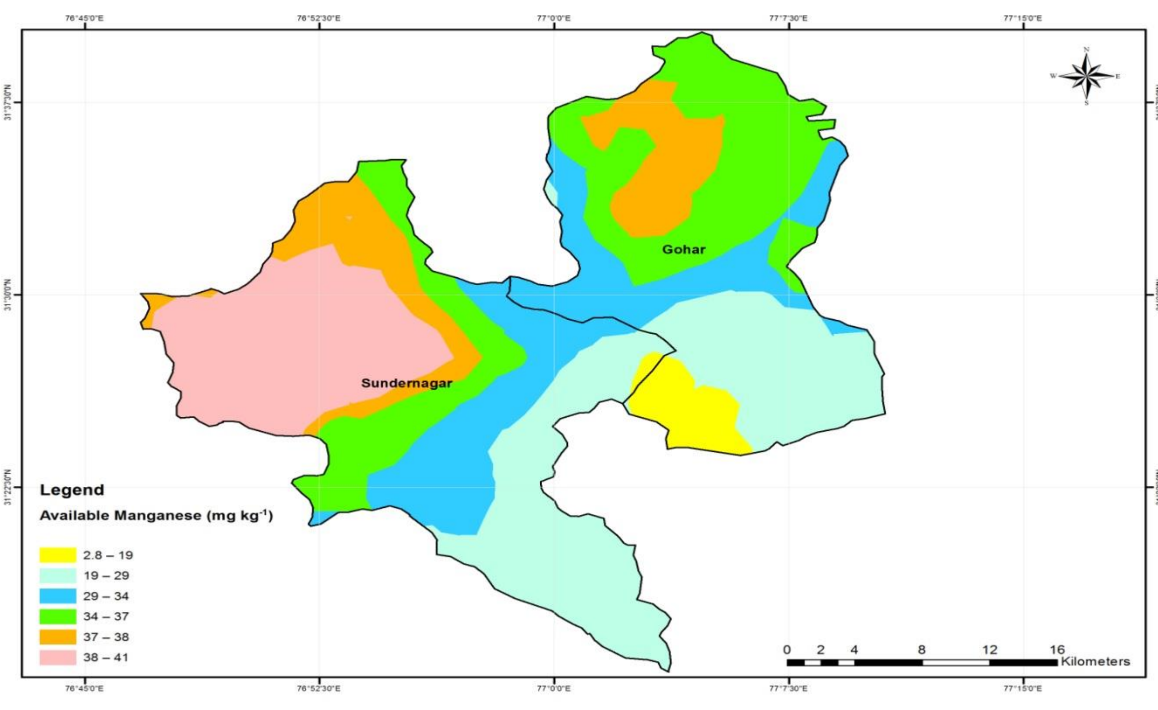

Figure 4.14 Spatial distribution map of available manganese (0-15cm)

were observed in surface and sub-surface soil samples of Nalni and Dol villages under Sundernagar block, respectively. The DTPA-extractable Mn content decreased with increase in soil depth. All the pea growing soils in the region are high in available Mn status (Table 3.5). The spatial distribution map of DTPA-extractable manganese of pea growing areas is presented in Figure 4.14.

Available manganese content varied among different locations and it was higher in surface soils than sub-surface layers, which may be due to low pH and high organic matter in surface soil layers. The results confirm the findings of Tripathi *et al*. (1994), Doneriya *et al.* (2013) and Kakar *et al.* (2018b).

4.1.3.3 DTPA-extractable copper (Cu)

The DTPA-extractable Cu content ranged from 0.06 to 4.85 mg kg^{-1} and 0.10 to 4.10 mg kg^{-1} with mean values of 1.42 mg kg^{-1} and 1.23 mg kg^{-1} in the surface and sub-surface soils, respectively (Table 4.6). The lowest (0.30 mg kg^{-1} and 0.27 mg kg^{-1}) and highest (3.76 mg kg^{-1} and 3.55 mg kg^{-1}) mean DTPA-extractable Cu content in surface and sub-surface samples were recorded in Majhar and Chatar villages under Sundernagar block, respectively. The DTPA-extractable Cu content decreased with increase in soil depth. The overall status of available Cu in pea growing soils is high (Table 3.5). The spatial distribution map of DTPA-extractable copper of pea growing areas is presented in Figure 4.15.

The variation of soil available copper content among different locations might be due to variation in soil pH, organic matter and clay content. A decreasing trend of available copper content was observed with increase in depth and surface soils were rich in copper content, which might be due to high organic matter and regular addition of manures and fertilizers to surface soils. The results are in line with those of Thakur and Bhandari (1986) and Sharma and Kanwar (2010). Mahajan *et al.* (2007) also reported high levels of DTPA-Cu in the soils of Himachal Pradesh.

4.1.3.4 DTPA-extractable zinc (Zn)

A perusal of data presented in Table 4.6 reveals that DTPA-extractable Zn content varied from 0.04 to 7.05 mg kg^{-1} and 0.03 to 5.85 mg kg^{-1}, with mean values of 2.13 mg kg^{-1} and 1.83 mg kg^{-1} in surface and sub-surface soils, respectively. In surface and sub-surface samples, the lowest (0.33 mg kg^{-1} and 0.22 mg kg^{-1}) and highest (5.19 mg kg^{-1} and 4.30 mg kg^{-1}) mean

DTPA-extractable Zn content were recorded in Gullas village under Sundernagar block and Gohar village under Gohar block, respectively. In general, the DTPA-extractable Zn content in district soils decreased with increase in soil depth. By comparing the values with Table 3.5, it can be inferred that samples falls in low, medium and high range, respectively. The spatial distribution map of DTPA-extractable zinc of pea growing areas is presented in Figure 4.16.

The variation in amount of zinc might be due to difference in organic carbon, soil pH and other management practices. Similar results are also observed by Chander *et al.* (2014) and Kakar *et al.* (2018b). Thakur and Bhandari (1986) reported that DTPA-extractable Zn varied from 0.56 to 6.76 mg kg^{-1} in Saproon valley of Himachal Pradesh.

4.2 NUTRIENT INDICES OF SOIL

A perusal of data presented in Table 4.7 reveals that 94.81, 2.96, 2.96 and 22.22 per cent surface soil samples falls under low category with respect to N, S, Cu and Zn, respectively. All the soils of district are rich in P, K, Ca, Mg, Fe and Mn. Nutrient indices indicate that soils of pea growing area of the district, as regards the nutrient status are high in available phosphorus (2.97), available potassium (2.47), available sulphur (2.94), exchangeable calcium (3.00), exchangeable magnesium (3.00), DTPA- extractable iron (3.00), manganese (2.99) and copper (2.66). However, with respect to available nitrogen (1.05) and DTPA-extractable zinc (2.00), soils are low and medium in nutrient status, respectively. Therefore, the surface soils of pea growing region differed in nutrient status and may respond differently to fertilizer application.

For sub-surface soils, nutrient index values varied from 1.01 to 3.00 (Table 4.8). The P (2.84), exchangeable Ca (3.00), exchangeable Mg (3.00), S (2.81), DTPA-Fe (3.00), Mn (2.99) and Cu (2.56) were falling in high categories, respectively. However, nutrient indices indicate that sub-surface soil samples were categorized low for available N (1.01), medium for K (2.17) and DTPA-extractable Zn (1.88).

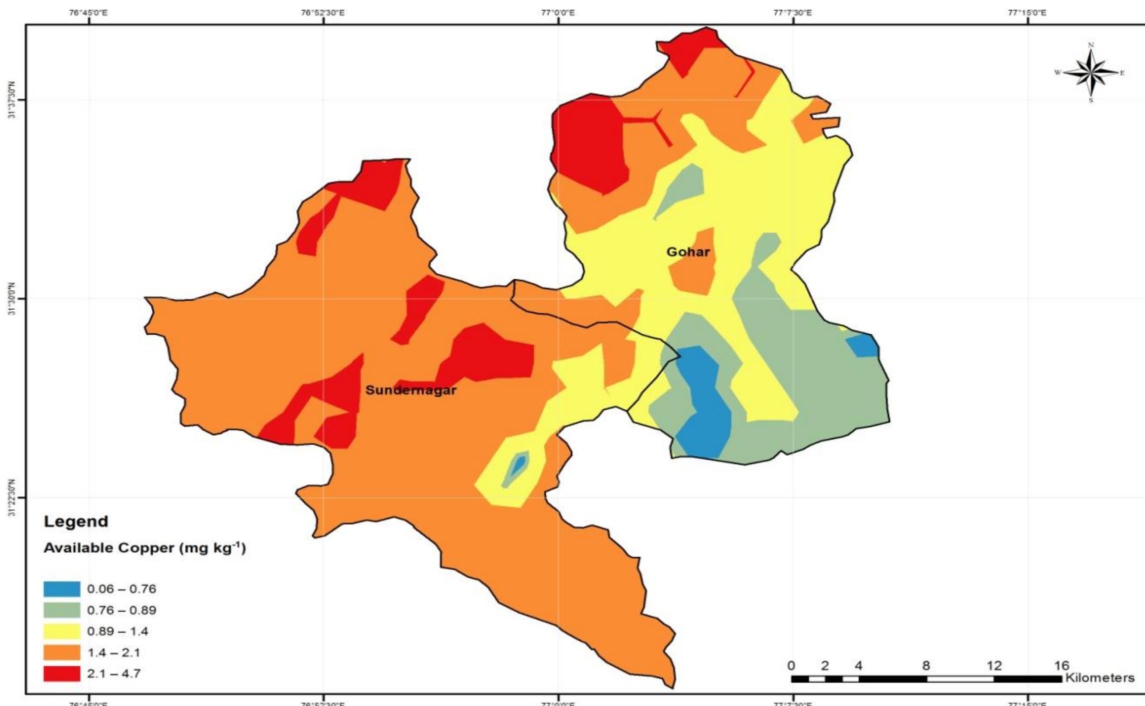

Figure 4.15 Spatial distribution map of available copper (0-15cm)

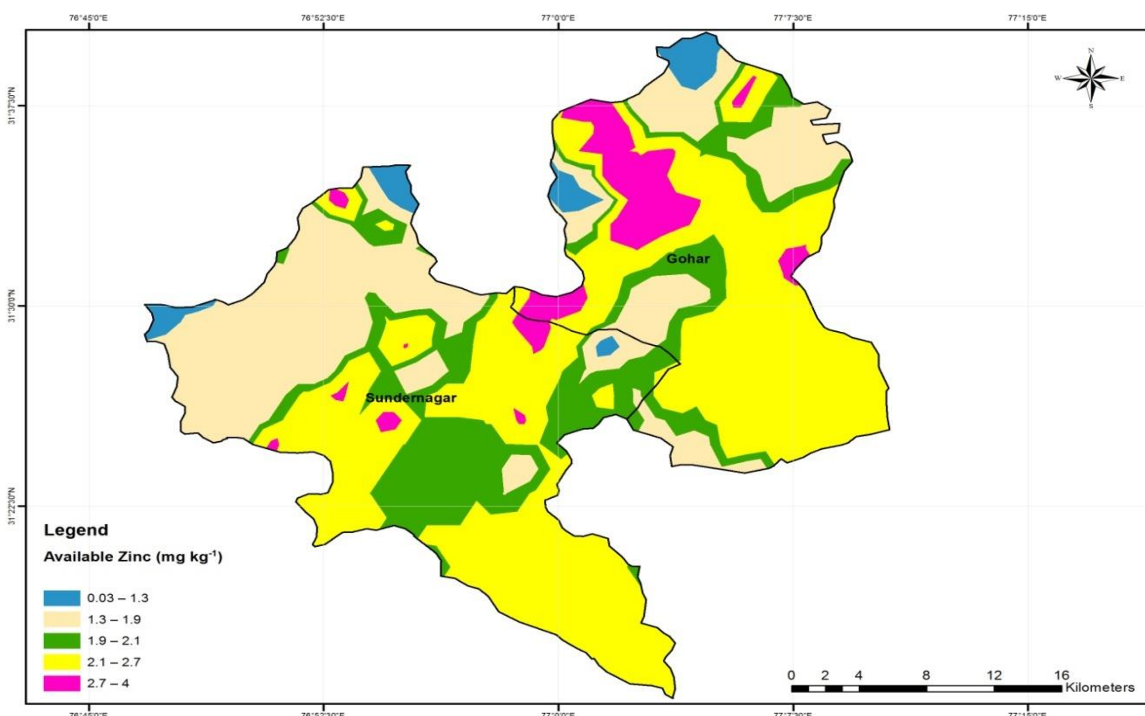

Figure 4.16 Spatial distribution map of available zinc (0-15cm)

Table 4.7 Nutrient Indices of the surface soil of vegetable growing areas of Mandi district

Nutrient	Percentage of samples rating			Nutrient Index	Nutrient Status
	Low	Medium	High		
Nitrogen	94.81	5.19	-	1.05	Low
Phosphorus	-	2.96	97.04	2.97	High
Potassium	-	53.33	46.67	2.47	High
Calcium	-	-	100	3.00	High
Magnesium	-	-	100	3.00	High
Sulphur	2.96	-	97.04	2.94	High
Iron	-	-	100	3.00	High
Manganese	-	0.74	99.26	2.99	High
Copper	2.96	28.15	68.89	2.66	High
Zinc	22.22	55.56	22.22	2.00	Medium

Table 4.8 Nutrient Indices of the sub-surface soil of vegetable growing areas

Nutrient	Percentage of samples rating			Nutrient Index	Nutrient Status
	Low	Medium	High		
Nitrogen	98.51	1.49	-	1.01	Low
Phosphorus	2.96	10.37	86.67	2.84	High
Potassium	7.41	68.15	24.44	2.17	Medium
Calcium	-	-	100	3.00	High
Magnesium	-	-	100	3.00	High
Sulphur	9.63	-	90.37	2.81	High
Iron	-	-	100	3.00	High
Manganese	-	0.74	99.26	2.99	High
Copper	5.19	33.33	61.48	2.56	High
Zinc	28.15	55.56	16.29	1.88	Medium

4.3 MACRONUTRIENTS AND MICRONUTRIENTS CONCENTRATION IN PLANTS

The leaf samples of pea were also analyzed for their nutrient contents and the results are presented below (Table 4.9, 4.10 and 4.11).

4.3.1 Macronutrients

The N, P and K content in the leaves of pea varied from 0.28 to 3.80, 0.11 to 0.32 and 0.10 to 1.66 per cent with mean values of 2.03, 0.20 and 1.06 per cent, respectively (Table 4.9). The lowest (1.06, 0.12 and 0.30%) mean N, P and K content were recorded in leaf samples collected from Saloyi village (Gohar block), Sakor village (Sundernagar block) and Majothi village (Gohar block), respectively. While, highest (3.16, 0.27 and 1.55%) mean values of N, P

Table 4.9 Leaf nitrogen, phosphorus and potassium content in vegetable growing areas

Sr. No.	Location	N (%)	P (%)	K (%)
1	Majothi	2.40-3.69 (3.13)	0.22-0.29 (0.26)	0.25-0.36 (0.30)
2	Bhawanipur	2.1-3.33 (2.70)	0.22-0.31 (0.26)	0.60-0.78 (0.68)
3	Kharsi	1.62-3.08 (2.36)	0.18-0.29 (0.23)	0.78-1.07 (0.92)
4	Thachi	1.56-3.69 (2.29)	0.15-0.23 (0.19)	0.70-1.00 (0.86)
5	Nalahar	2.12-3.80 (3.16)	0.16-0.24 (0.20)	1.18-1.42 (1.30)
6	Sheladhar	1.90-2.46 (2.20)	0.13-0.25 (0.20)	0.77-1.10 (0.95)
7	Deem	0.89-2.57 (1.75)	0.11-0.18 (0.14)	0.92-1.14 (1.03)
8	Bassi	0.56-2.68 (1.41)	0.13-0.28 (0.18)	0.75-1.18 (0.92)
9	Duga	2.57-3.69 (3.13)	0.19-0.27 (0.23)	1.50-1.59 (1.55)
10	Kotla	1.45-3.36 (2.40)	0.17-0.26 (0.22)	0.93-1.46 (1.18)
11	Bhava	2.24-2.68 (2.38)	0.14-0.20 (0.17)	1.04-1.37 (1.15)
12	Daan	1.12-3.36 (2.24)	0.13-0.27 (0.18)	1.25-1.66 (1.50)
13	Taneli	2.12-3.47 (2.90)	0.17-0.24 (0.21)	1.04-1.36 (1.23)
14	Gohar	1.90-2.57 (2.19)	0.23-0.28 (0.24)	0.86-1.18 (1.05)
15	Khayod	1.79-2.12 (1.93)	0.21-0.30 (0.25)	0.81-1.28 (1.00)
16	Dari	1.79-2.01 (1.90)	0.19-0.27 (0.22)	0.86-1.00 (0.93)
17	Masog	2.35-2.91 (2.57)	0.14-0.21 (0.18)	0.98-1.16 (1.06)
18	Chachyot	2.40-3.24 (2.88)	0.13-0.24 (0.18)	1.20-1.46 (1.32)
19	Bharjodu	2.29-2.68 (2.45)	0.19-0.27 (0.22)	1.06-1.22 (1.13)
20	Kot	2.07-2.96 (2.55)	0.22-0.32 (0.27)	1.10-1.32 (1.19)
21	Naugraun	2.24-2.91 (2.57)	0.18-0.25 (0.22)	1.06-1.62 (1.28)
22	Saloyi	0.28-1.79 (1.06)	0.24-0.26 (0.24)	0.72-0.94 (0.79)
23	Kutwachi	1.12-1.90 (1.58)	0.13-0.19 (0.17)	0.90-1.11 (0.99)
24	Kharadhar	2.01-2.4 (2.14)	0.22-0.24 (0.23)	1.04-1.12 (1.06)
25	Sakor	1.17-2.74 (1.64)	0.12-0.14 (0.12)	0.80-0.95 (0.88)
26	Sangli	0.89-1.84	0.12-0.14	0.78-1.11

		(1.45)	(0.13)	(0.93)
27	Thamadi	0.89-1.56 (1.20)	0.12-0.15 (0.14)	0.70-1.12 (0.89)
28	Chuni	1.12-2.35 (1.73)	0.18-0.24 (0.20)	1.04-1.25 (1.16)
29	Rohanda	1.40-1.96 (1.73)	0.16-0.22 (0.20)	1.00-1.08 (1.04)
30	Ghasnu	1.51-2.29 (1.84)	0.15-0.26 (0.21)	1.00-1.31 (1.12)
31	Kamand	1.28-1.79 (1.54)	0.16-0.18 (0.17)	0.10-1.00 (0.68)
32	Kathel	1.34-2.12 (1.78)	0.17-0.22 (0.20)	1.12-1.24 (1.18)
33	Okhal	1.17-2.01 (1.69)	0.14-0.22 (0.18)	1.11-1.23 (1.17)
34	Majhar	1.17-3.30 (2.23)	0.14-0.27 (0.20)	1.11-1.47 (1.29)
35	Majhothi	2.18-2.57 (2.40)	0.14-0.26 (0.20)	1.20-1.32 (1.25)
36	Rohangalu	1.79-2.63 (2.23)	0.17-0.26 (0.21)	0.97-1.12 (1.04)
37	Laag	1.28-1.45 (1.36)	0.17-0.28 (0.23)	0.88-0.92 (0.90)
38	Nalni	1.40-1.79 (1.59)	0.12-0.20 (0.16)	0.92-0.97 (0.94)
39	Dol	1.28-2.29 (1.78)	0.13-0.14 (0.13)	0.92-1.22 (1.07)
40	Dharli	2.01-2.12 (2.06)	0.15-0.21 (0.18)	1.16-1.19 (1.18)
41	Ghurangalu	1.62-1.96 (1.79)	0.16-0.17 (0.16)	1.08-1.12 (1.10)
42	Jai Devi	1.69-1.71 (1.70)	0.16-0.24 (0.20)	1.02-1.12 (1.07)
43	Kandyah	1.45-2.12 (1.76)	0.18-0.27 (0.24)	1.12-1.24 (1.22)
44	Chatar	1.06-1.56 (1.35)	0.21-0.26 (0.23)	1.04-1.17 (1.11)
45	Rada	1.23-1.62 (1.45)	0.12-0.20 (0.15)	0.97-1.02 (0.99)
46	Khilra	1.4-1.56 (1.47)	0.13-0.18 (0.16)	1.00-1.16 (1.09)
47	Maun	1.45	0.13	1.02
48	Gullas	1.68	0.25	1.16
49	Ghiri	1.96	0.22	1.08
	Range	**0.28-3.80**	**0.11-0.32**	**0.10-1.66**
	Mean	**2.03**	**0.20**	**1.06**
	SE (±)	**0.06**	**0.004**	**0.02**
	CV (%)	**34.76**	**26.15**	**23.06**

**Values in parenthesis indicate mean*

and K were recorded in leaf samples of Nalahar, Kot and Duga villages under Gohar block, respectively. Considering the critical limits for pea crop (Table 3.6), only 52.59, 28.15 and 89.63 per cent samples found in sufficient range for N, P and K, respectively (Table 4.12) (Figure 4.27). The spatial distribution maps of leaf N, P and K of pea growing areas are presented in Figure 4.17, 4.18 and 4.19.

The soil analysis data shows that soils are low in available nitrogen and rich in available P and K. It appears the extractant used for available K are quite suitable for soils of the area as soil and plant analysis data are in complete agreement with each other. The observations are in agreement with those made by Thakur (1979), Mogta and Sharma (2018) and Kumari and Tripathi (2018).

The data in Table 4.10 reveals that leaf Ca, Mg and S content ranged from 0.13 to 2.10, 0.08 to 0.37 and 0.26 to 0.96 per cent with mean values of 1.30, 0.24 and 0.71 per cent, respectively. The lowest (0.64, 0.13 and 0.44%) mean values of Ca, Mg and S content were recorded in leaf samples of Kharsi, Bassi and Bhawanipur villages under Gohar block, respectively. Whereas, highest (1.92 and 0.32%) mean values of Ca and Mg content were recorded in the leaf samples of Chachyot village under Gohar block and S (0.86%) content in Ghiri village under Sundernagar block, respectively. As per critical limits for secondary nutrients (Table 3.6), 92.59 and 87.41 per cent leaf samples are in sufficient range for Ca and Mg and 59.26 per cent samples are high in S (Table 4.12) (Figure 4.28). The spatial distribution maps of leaf Ca, Mg and S of pea growing areas are presented in Figure 4.20, 4.21 and 4.22.

The variation in leaf Ca, Mg and S content could be ascribed to variation in soil available Ca, Mg and S content, application of high quantity of manures and fertilizers and overall pedoclimatic conditions. The results are in line with the findings of Mahler *et al.* (1988), Campbell (2000) and Kakar *et al.* (2018a).

4.3.2 Micronutrients

The data presented in Table 4.11 shows that pea leaf iron content ranged from 91.4 to 790.2 ppm with a mean value of 318.8 ppm. The lowest (96.5 ppm) and highest (577.5 ppm) mean values of Fe content were recorded in Bhava village (Gohar block) and Okhal village (Sundernagar block), respectively. Table 4.12 reveals that all samples are high in status with respect to leaf iron. The spatial distribution map of leaf Fe of pea growing areas is presented in Figure 4.23.

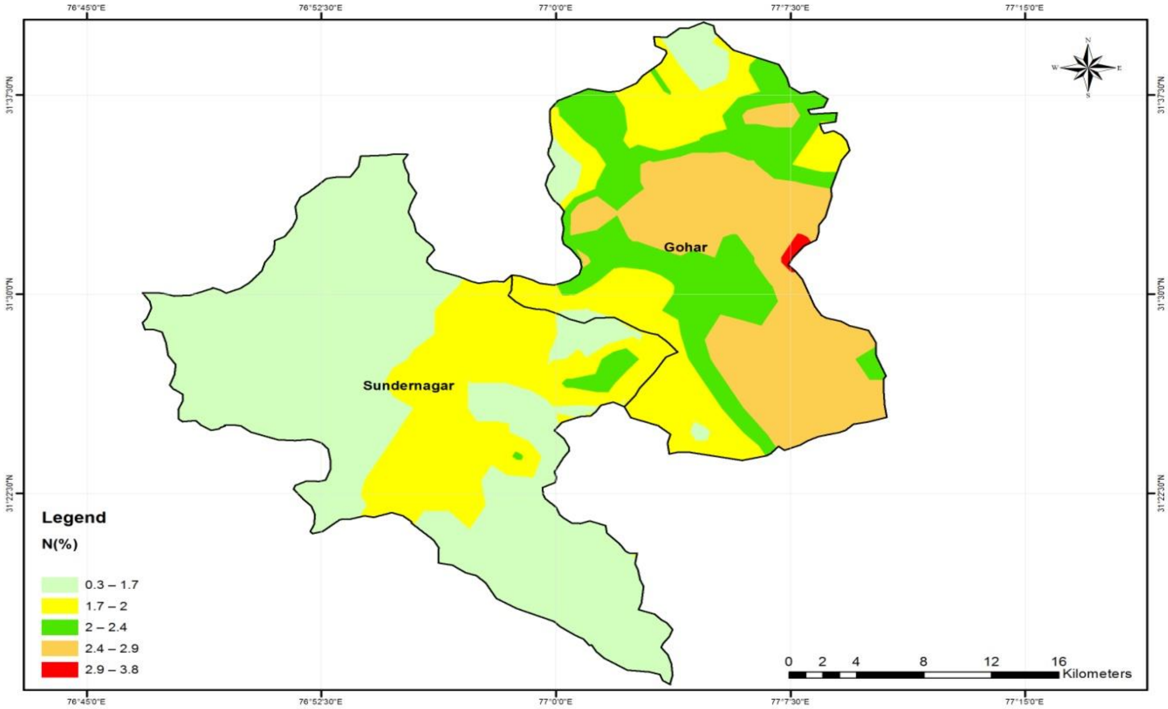

Figure 4.17 Spatial distribution map of leaf nitrogen

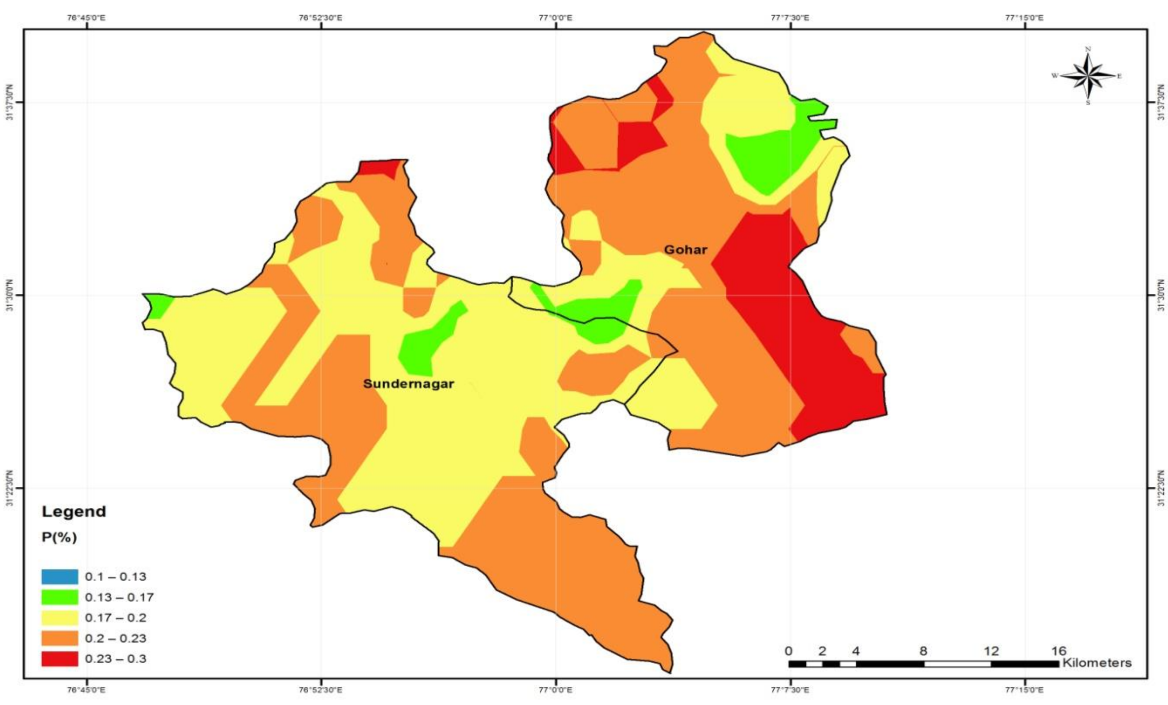

Figure 4.18 Spatial distribution map of leaf phosphorus

Table 4.10 Leaf calcium, magnesium and sulphur content in vegetable growing soils of the district

Sr. No.	Location	Ca (%)	Mg (%)	S (%)
1	Majothi	0.70-0.86 (0.79)	0.10-0.19 (0.15)	0.43-0.63 (0.52)
2	Bhawanipur	0.84-0.99 (0.93)	0.11-0.18 (0.14)	0.36-0.53 (0.44)
3	Kharsi	0.13-1.67 (0.64)	0.13-0.16 (0.15)	0.53-0.76 (0.63)
4	Thachi	1.54-1.72 (1.61)	0.22-0.30 (0.26)	0.71-0.83 (0.76)
5	Nalahar	1.65-1.96 (1.81)	0.22-0.32 (0.27)	0.30-0.82 (0.60)
6	Sheladhar	1.11-1.43 (1.30)	0.18-0.24 (0.21)	0.26-0.65 (0.49)
7	Deem	0.76-1.52 (1.15)	0.09-0.19 (0.15)	0.61-0.86 (0.71)
8	Bassi	0.60-1.40 (1.01)	0.08-0.17 (0.13)	0.46-0.78 (0.60)
9	Duga	1.36-1.79 (1.57)	0.19-0.27 (0.23)	0.78-0.85 (0.81)
10	Kotla	1.22-1.90 (1.48)	0.21-0.33 (0.26)	0.71-0.86 (0.77)
11	Bhava	1.01-1.13 (1.05)	0.21-0.23 (0.22)	0.61-0.86 (0.71)
12	Daan	0.80-1.06 (0.95)	0.18-0.35 (0.26)	0.62-0.75 (0.68)
13	Taneli	1.18-1.93 (1.62)	0.25-0.32 (0.29)	0.75-0.85 (0.80)
14	Gohar	1.64-1.96 (1.80)	0.21-0.26 (0.24)	0.71-0.78 (0.74)
15	Khayod	1.40-1.66 (1.54)	0.21-0.24 (0.23)	0.61-0.76 (0.68)
16	Dari	1.40-1.71 (1.55)	0.22-0.24 (0.23)	0.69-0.84 (0.75)
17	Masog	1.64-1.80 (1.73)	0.27-0.35 (0.30)	0.58-0.86 (0.74)
18	Chachyot	1.64-2.10 (1.92)	0.26-0.37 (0.32)	0.55-0.81 (0.69)
19	Bharjodu	1.67-1.82 (1.75)	0.26-0.28 (0.27)	0.75-0.83 (0.79)
20	Kot	1.55-1.79 (1.64)	0.25-0.27 (0.26)	0.81-0.87 (0.84)
21	Naugraun	1.42-1.65 (1.53)	0.25-0.26 (0.25)	0.80-0.88 (0.83)
22	Saloyi	0.64-1.04 (0.88)	0.09-0.20 (0.15)	0.65-0.74 (0.69)
23	Kutwachi	0.90-1.23 (1.09)	0.19-0.24 (0.22)	0.48-0.62 (0.56)
24	Kharadhar	1.19-1.30 (1.22)	0.25-0.27 (0.26)	0.75-0.80 (0.77)
25	Sakor	1.04-1.42 (1.25)	0.19-0.25 (0.21)	0.63-0.78 (0.70)

26	Sangli	0.72-1.34 (1.10)	0.18-0.29 (0.25)	0.45-0.68 (0.58)
27	Thamadi	0.70-1.10 (0.92)	0.18-0.31 (0.24)	0.36-0.73 (0.52)
28	Chuni	1.05-1.59 (1.33)	0.20-0.31 (0.26)	0.65-0.77 (0.71)
29	Rohanda	1.31-1.44 (1.38)	0.25-0.29 (0.27)	0.78-0.88 (0.82)
30	Ghasnu	1.10-1.48 (1.24)	0.24-0.32 (0.28)	0.61-0.96 (0.83)
31	Kamand	1.20-1.32 (1.25)	0.23-0.26 (0.24)	0.75-0.85 (0.80)
32	Kathel	1.16-1.54 (1.36)	0.23-0.30 (0.27)	0.70-0.86 (0.77)
33	Okhal	1.12-1.51 (1.34)	0.20-0.30 (0.26)	0.48-0.90 (0.65)
34	Majhar	1.17-1.78 (1.47)	0.20-0.34 (0.27)	0.72-0.80 (0.76)
35	Majhothi	1.34-1.44 (1.39)	0.27-0.31 (0.29)	0.79-0.85 (0.82)
36	Rohangalu	1.19-1.54 (1.39)	0.24-0.31 (0.27)	0.63-0.76 (0.69)
37	Laag	1.08-1.17 (1.12)	0.23-0.25 (0.24)	0.75-0.83 (0.79)
38	Nalni	1.06-1.27 (1.16)	0.25-0.29 (0.27)	0.85-0.87 (0.85)
39	Dol	1.11-1.56 (1.33)	0.23-0.28 (0.25)	0.75-0.78 (0.76)
40	Dharli	1.42-1.50 (1.46)	0.28-0.29 (0.28)	0.76-0.80 (0.78)
41	Ghurangalu	1.12-1.25 (1.18)	0.22-0.24 (0.23)	0.75-0.81 (0.78)
42	Jai Devi	1.02-1.09 (1.05)	0.22-0.23 (0.23)	0.63-0.71 (0.67)
43	Kandyah	1.17-1.38 (1.27)	0.22-0.28 (0.25)	0.74-0.86 (0.79)
44	Chatar	0.99-1.17 (1.09)	0.18-0.23 (0.21)	0.68-0.83 (0.73)
45	Rada	0.91-1.28 (1.11)	0.20-0.24 (0.22)	0.55-0.86 (0.70)
46	Khilra	0.84-1.08 (0.95)	0.23-0.24 (0.23)	0.46-0.50 (0.48)
47	Maun	1.14	0.25	0.56
48	Gullas	1.25	0.28	0.70
49	Ghiri	1.44	0.28	0.86
	Range	**0.13-2.10**	**0.08-0.37**	**0.26-0.96**
	Mean	**1.30**	**0.24**	**0.71**
	SE (±)	**0.03**	**0.005**	**0.01**
	CV (%)	**26.73**	**22.52**	**19.25**

**Values in parenthesis indicate mean*

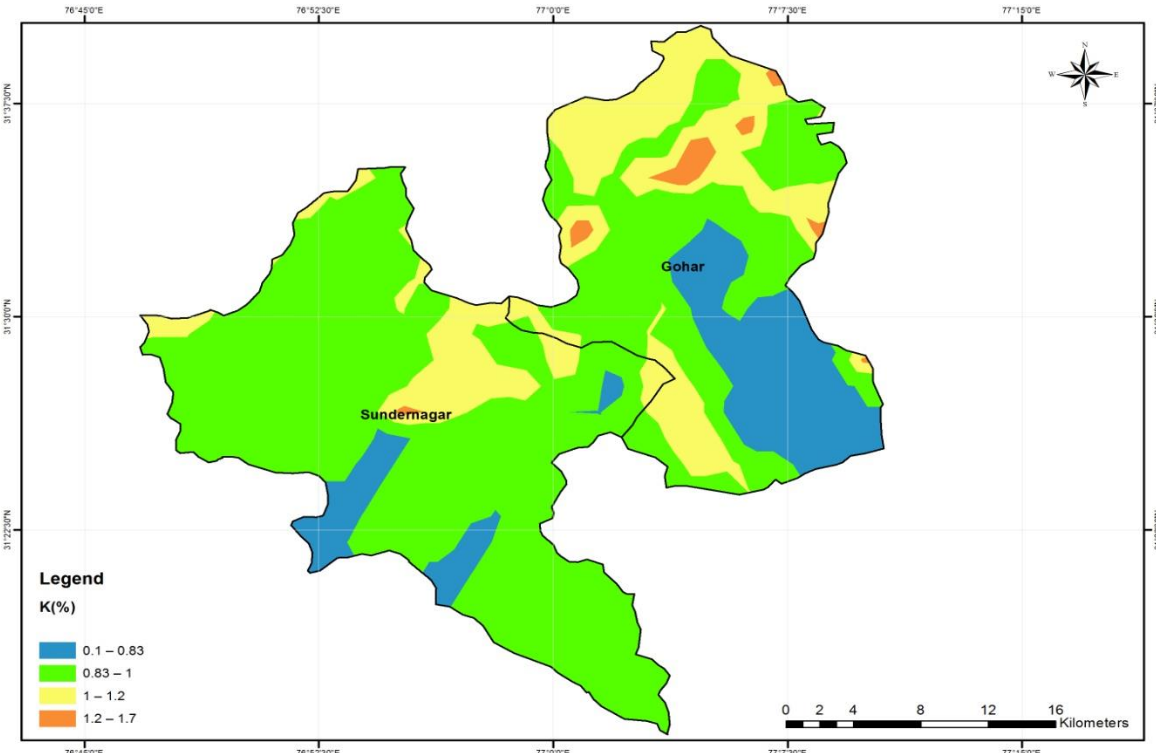

Figure 4.19 Spatial distribution map of leaf potassium

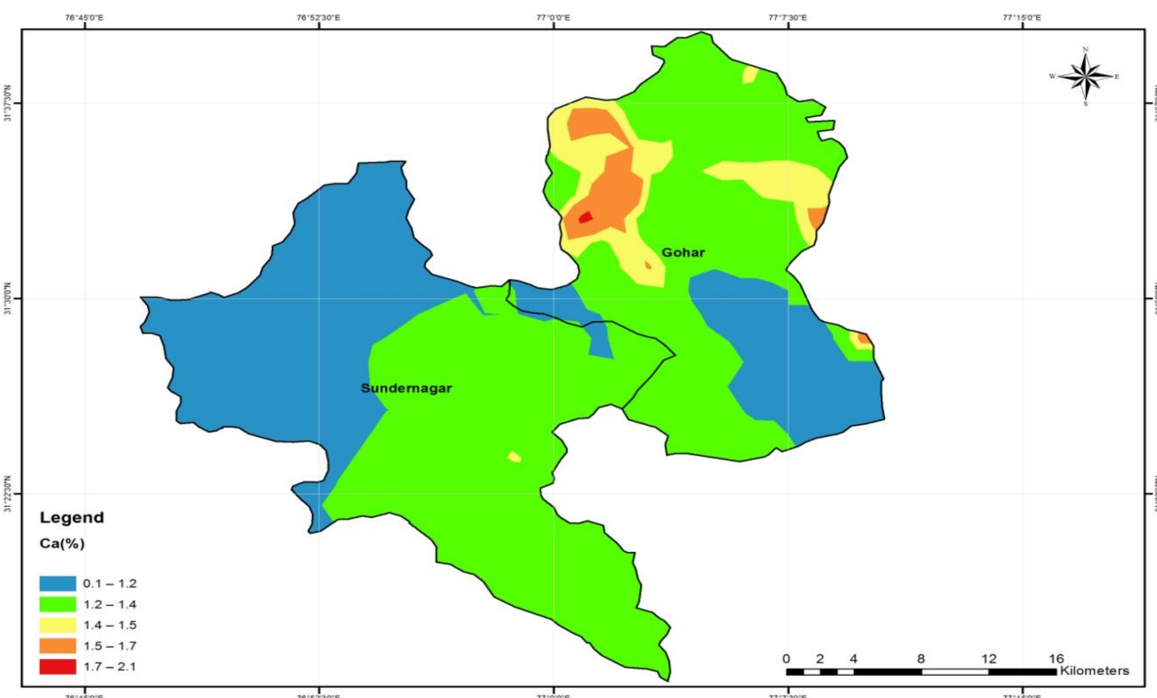

Figure 4.20 Spatial distribution map of leaf calcium

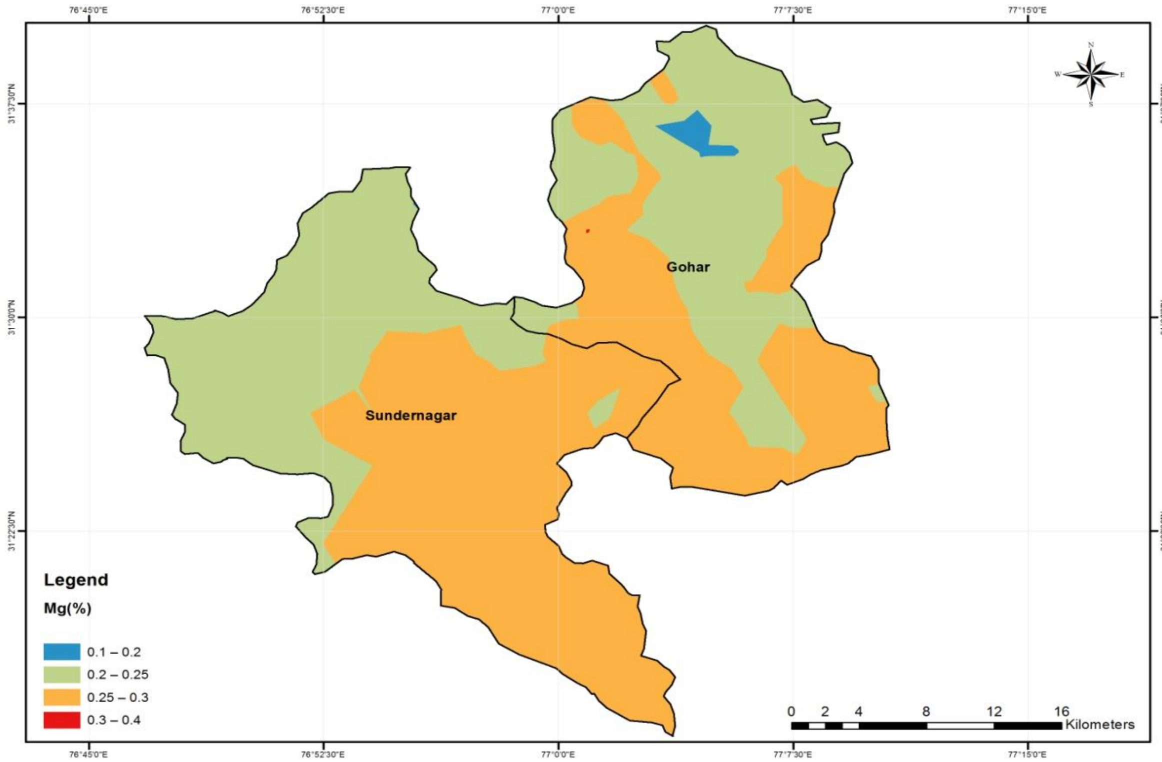

Figure 4.21 Spatial distribution map of leaf magnesium

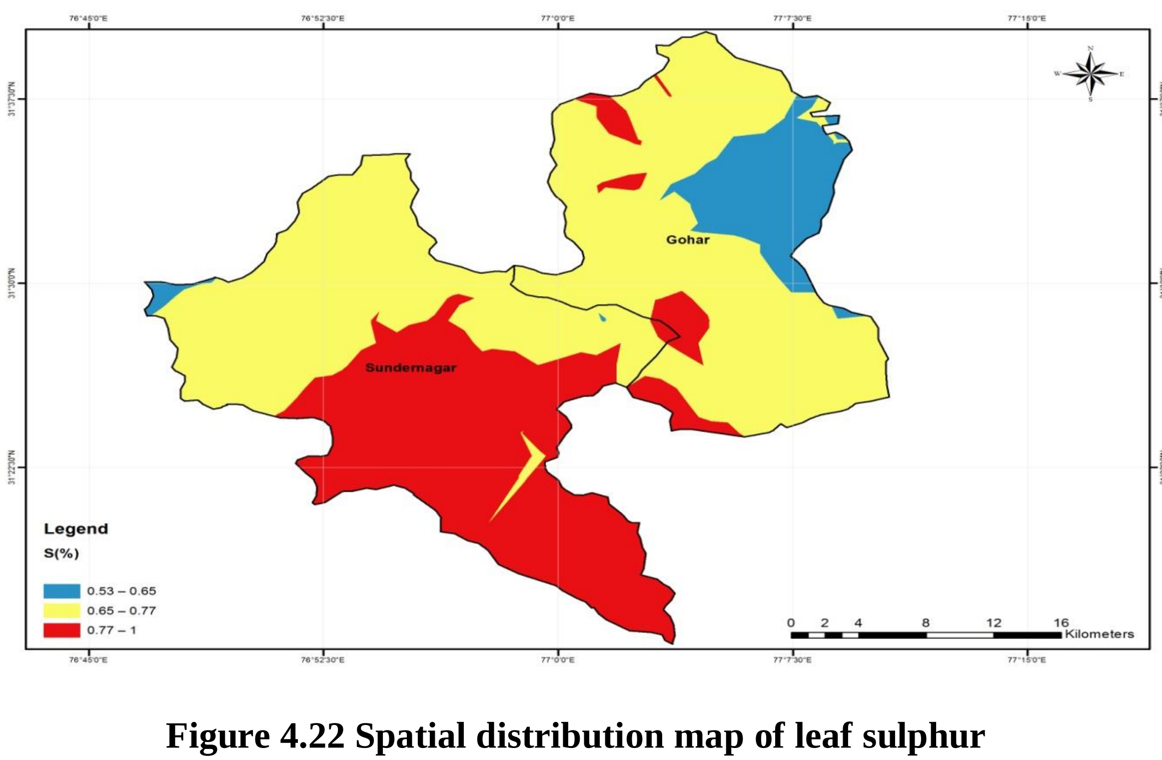

Figure 4.22 Spatial distribution map of leaf sulphur

The data for leaf manganese content (Table 4.11) indicates that its values ranged from 21.0 to 380.6 ppm with a mean value of 105.8 ppm. In Duga and Sheladhar villages under Gohar block recorded the lowest (21.9 ppm) and highest (265.3 ppm) mean values of leaf Mn content in leaf samples. About 66.67 per cent samples are high in Mn status (Table 4.12). The spatial distribution map of leaf Mn of pea growing areas is presented in Figure 4.24.

Further, it can be inferred from the Table 4.11 that leaf copper content ranged from 4.4 to 16.0 ppm, with a mean value of 9.4 ppm. The lowest (4.7 ppm) and highest (13.7 ppm) mean values of leaf Cu content were recorded in leaf samples of Majothi and Chachyot villages under Gohar block, respectively. Table 4.12 indicates that 88.89 per cent samples are sufficient in leaf Cu status. The spatial distribution map of leaf Cu of pea growing areas is presented in Figure 4.25.

The leaf zinc content of pea leaf varied from 19.0 to 213.8 ppm with a mean value of 105.0 ppm (Table 4.11). The leaf samples of Deem village (Gohar block) and Majhar village under Sundernagar block recorded the lowest (36.3 ppm) and highest (193.8 ppm) mean values of Zn content. About 65.93 per cent samples are high in leaf Zn status (Table 4.12) (Figure 4.29). The spatial distribution map of leaf Zn of pea growing areas is presented in Figure 4.26.

A perusal of the Table 4.12 reveals that the majority of leaf samples for Fe, Mn, Cu and Zn micronutrients are medium to high in status owing to suitable pH for micronutrients availability and uptake, parent material (gypsiferrous and ferruginous) and soil organic matter. The results are in accordance with the findings of Sharma and Kanwar (2010), Khajuria (2010), Kakar *et al.* (2018a) and Mogta and Sharma (2018).

Soil analysis showed that available N, Zn, S and Cu were low in 94.81, 22.22, 2.96 and 2.96 per cent pea growing villages, respectively, whereas, leaf analysis revealed that 42.96, 0.74, 11.11 and 11.11 per cent pea growing villages were deficient in these nutrients, respectively (Table 4.7 and 4.12). Soil analysis showed no deficiency of P, K, Ca, Mg, Fe and Mn, whereas, leaf analysis has shown 71.85, 3.70, 7.41, 1.48, 0.00 and 5.93 per cent samples to be low in pea leaf content, respectively.

Table 4.11 Leaf iron, manganese, copper and zinc content in vegetable growing areas of Mandi district

Sr. No.	Location	Fe (ppm)	Mn (ppm)	Cu (ppm)	Zn (ppm)
1	Majothi	190.0-250.0 (218.7)	25.0-48.2 (38.3)	4.4-4.8 (4.7)	41.8-118.2 (85.7)
2	Bhawanipur	216.2-284.4 (257.3)	53.4-67.4 (63.3)	5.6-7.2 (6.5)	42.6-62.0 (53.0)
3	Kharsi	216.2-374.4 (298.3)	61.0-103.6 (85.6)	4.8-6.8 (5.7)	41.8-73.8 (60.9)
4	Thachi	284.4-348.6 (312.4)	77.2-155.0 (120.7)	6.8-11.0 (8.9)	57.6-90.0 (71.2)
5	Nalahar	374.4-410.8 (392.1)	84.4-120.0 (100.5)	6.8-11.8 (9.2)	123.0-191.0 (162.6)
6	Sheladhar	166.4-186.6 (178.6)	143.8-380.6 (265.3)	11.0-13.8 (12.6)	66.0-118.2 (85.7)
7	Deem	271.2-304.2 (286.6)	129.8-229.6 (178.4)	6.8-13.0 (10.3)	31.4-44.8 (36.3)
8	Bassi	190.0-284.4 (241.5)	40.2-280.0 (200.1)	5.0-6.8 (5.8)	67.0-85.6 (78.3)
9	Duga	374.4-410.8 (392.6)	21.0-22.8 (21.9)	8.0-9.0 (8.5)	85.6-118.2 (101.9)
10	Kotla	102.0-114.2 (108.4)	97.2-111.0 (103.9)	6.8-11.0 (8.9)	173.8-194.4 (186.4)
11	Bhava	91.4-102.0 (96.5)	67.4-69.2 (68.6)	6.8-11.6 (9.1)	77.0-123.0 (96.7)
12	Daan	160.0-186.6 (176.5)	30.9-92.2 (64.1)	9.6-12.4 (10.7)	51.2-73.2 (63.5)
13	Taneli	374.4-752.4 (552.5)	26.0-154.4 (92.5)	8.6-12.6 (10.5)	90.0-171.8 (128.3)
14	Gohar	304.2-410.8 (368.7)	48.2-155.0 (102.3)	10.2-16.0 (12.9)	143.6-173.8 (160.5)
15	Khayod	271.2-374.4 (325.6)	189.4-372.0 (264.3)	6.8-10.0 (8.4)	118.2-143.6 (128.3)
16	Dari	284.4-391.2 (350.0)	23.8-69.2 (53.5)	8.4-11.0 (9.7)	36.6-62.0 (51.0)
17	Masog	374.4-530.8 (432.1)	25.8-175.8 (118.7)	7.2-10.0 (8.5)	73.8-97.2 (87.0)
18	Chachyot	374.4-569.0 (444.9)	189.4-231.6 (216.9)	12.4-15.0 (13.7)	85.6-118.2 (102.3)
19	Bharjodu	304.2-410.8 (363.1)	77.2-111.0 (97.3)	12.4-14.2 (13.2)	67.0-123.0 (91.9)
20	Kot	284.4-374.4 (321.0)	77.2-129.8 (101.4)	10.2-13.6 (12.1)	57.6-90.0 (69.9)
21	Naugraun	216.2-331.2 (272.9)	92.2-129.8 (108.5)	8.4-12.4 (10.6)	164.2-189.4 (175.8)
22	Saloyi	160.0-304.2 (238.1)	97.2-154.4 (127.1)	8.4-11.0 (9.7)	112.2-143.6 (126.3)
23	Kutwachi	250.0-304.2 (275.1)	97.2-129.80 (112.4)	7.6-9.6 (8.5)	105.6-128.6 (119.1)
24	Kharadhar	216.2-391.2 (292.9)	67.40-97.2 (85.6)	9.0-11.6 (10.5)	64.0-97.2 (81.7)
25	Sakor	216.2-391.2 (295.7)	25.4-155.0 (87.6)	4.4-9.0 (6.3)	66.6-118.2 (88.9)

26	Sangli	250.0-304.2 (268.9)	53.4-110.2 (82.1)	4.8-8.4 (6.9)	66.2-89.8 (78.2)
27	Thamadi	190.0-331.2 (245.8)	84.4-110.2 (95.6)	6.8-10.0 (8.4)	74.2-82.8 (77.5)
28	Chuni	374.4-569.0 (444.9)	92.2-154.4 (114.6)	8.4-11.0 (9.5)	54.6-82.6 (67.5)
29	Rohanda	284.4-530.8 (402.1)	97.2-129.8 (110.2)	4.8-6.8 (5.7)	74.2-173.6 (121.4)
30	Ghasnu	331.2-391.2 (365.6)	40.2-111.0 (76.1)	6.8-10.0 (8.1)	74.4-89.8 (83.3)
31	Kamand	271.2-416.8 (354.1)	97.2-155.0 (127.3)	9.0-12.4 (10.8)	38.2-73.2 (55.2)
32	Kathel	304.2-391.2 (356.6)	48.2-103.6 (73.7)	6.8-13.0 (9.6)	74.2-105.6 (87.5)
33	Okhal	190.0-790.2 (577.5)	69.2-143.8 (105.5)	11.0-13.6 (12.3)	97.2-175.0 (123.1)
34	Majhar	250.0-304.2 (277.1)	175.8-189.4 (182.6)	11.6-12.2 (11.9)	173.6-213.9 (193.8)
35	Majhothi	284.4-410.8 (356.5)	84.4-155.0 (112.2)	9.6-12.4 (11.0)	19.0-194.4 (129.0)
36	Rohangalu	190.0-304.2 (248.1)	129.8-155.0 (138.2)	11.0-12.4 (11.7)	89.8-123.0 (110.3)
37	Laag	271.2-284.4 (277.8)	103.6-104.0 (103.8)	8.4-9.6 (9.0)	104.4-213.8 (159.1)
38	Nalni	391.2-410.8 (401.0)	67.4-97.2 (82.3)	6.8-7.6 (7.2)	173.8-211.2 (192.5)
39	Dol	304.2-374.4 (339.3)	40.2-61.0 (50.6)	5.6-6.8 (6.2)	143.6-213.8 (178.7)
40	Dharli	284.4-348.6 (316.5)	48.2-67.4 (57.8)	11.0-11.1 (11.1)	143.6-175.0 (159.3)
41	Ghurangalu	304.2-374.4 (339.3)	69.2-92.2 (80.7)	11.6-12.4 (12.0)	173.6-213.8 (193.7)
42	Jai Devi	216.2-284.4 (250.3)	23.8-69.2 (46.5)	8.4-11.0 (9.7)	82.6-85.6 (84.1)
43	Kandyah	328.0-388.0 (350.7)	40.2-97.2 (71.5)	10.0-12.4 (11.1)	54.2-64.2 (67.5)
44	Chatar	336.0-368.0 (351.3)	69.2-103.6 (88.3)	8.4-11.0 (9.7)	73.2-116.4 (95.7)
45	Rada	348.0-376.0 (362.7)	23.8-103.6 (55.9)	6.8-8.4 (7.6)	85.6-175.0 (127.9)
46	Khilra	319.2-338.0 (328.7)	48.2-97.2 (70.9)	9.6-11.6 (10.7)	97.2-155.6 (125.3)
47	Maun	271.2	129.8	11.0	104.4
48	Gullas	304.2	67.4	9.0	85.6
49	Ghiri	374.4	129.8	4.8	74.2
	Range	**91.4-790.2**	**21.0-380.6**	**4.4-16.0**	**19.0-213.8**
	Mean	**318.8**	**105.8**	**9.4**	**105.0**
	SE (±)	**9.8**	**5.4**	**0.2**	**4.0**
	CV (%)	**35.6**	**59.1**	**27.5**	**44.3**

**Values in parenthesis indicate mean*

Table 4.12 Per cent leaf samples falling in various categories of nutrient levels

Nutrient element	Per cent samples		
	Deficient	Sufficient	High
Nitrogen	42.96	52.59	4.45
Phosphorus	71.85	28.15	-
Potassium	3.70	89.63	6.67
Calcium	7.41	92.59	-
Magnesium	1.48	87.41	11.11
Sulphur	11.11	29.63	59.26
Iron	-	-	100
Manganese	5.93	27.40	66.67
Copper	11.11	88.89	-
Zinc	0.74	33.33	65.93

4.4 CORRELATION AMONG THE SOIL CHARACTERSTICS AND LEAF NUTRIENT STATUS

Simple correlation coefficients among the soils characteristics and leaf nutrient status were worked out on the data collected from the analysis of soil and leaf samples of the vegetable growing areas of the district. The data in this regard is presented in Table 4.13, 4.14 and 4.15.

4.4.1 Relationship of bulk density with pH, electrical conductivity and available nutrients

Bulk density was highly significantly and positively correlated with EC (r= 0.30**), DTPA-Cu (r= 0.24**), available P (r= 0.24**), Ca (r= 0.23**), K (r= 0.22**), S (r= 0.22**) and positively correlated with pH (r= 0.21*). However, it was highly significantly but negatively correlated with DTPA-Fe (r= -0.26**) and available N (r= -0.19*). Chaudhari *et al.* (2013) observed a significant and negative correlation of BD with primary nutrients. Bulk density is independent weather the soil is acidic or alkaline in nature.

4.4.2 Relationship of organic carbon, electrical conductivity, pH with available nutrients

A glance of data in Table 4.13 clearly indicates that soil organic carbon was highly significantly and positively correlated with DTPA-extractable Zn (r = 0.45**), Fe (r = 0.37**) and available N (r = 0.35**) and positively correlated with DTPA-extractable Mn (r = 0.21*). This indicates the importance of organic matter in promoting the availability of nutrient elements in the soils. While, it was highly significantly negatively correlated with exchangeable Ca

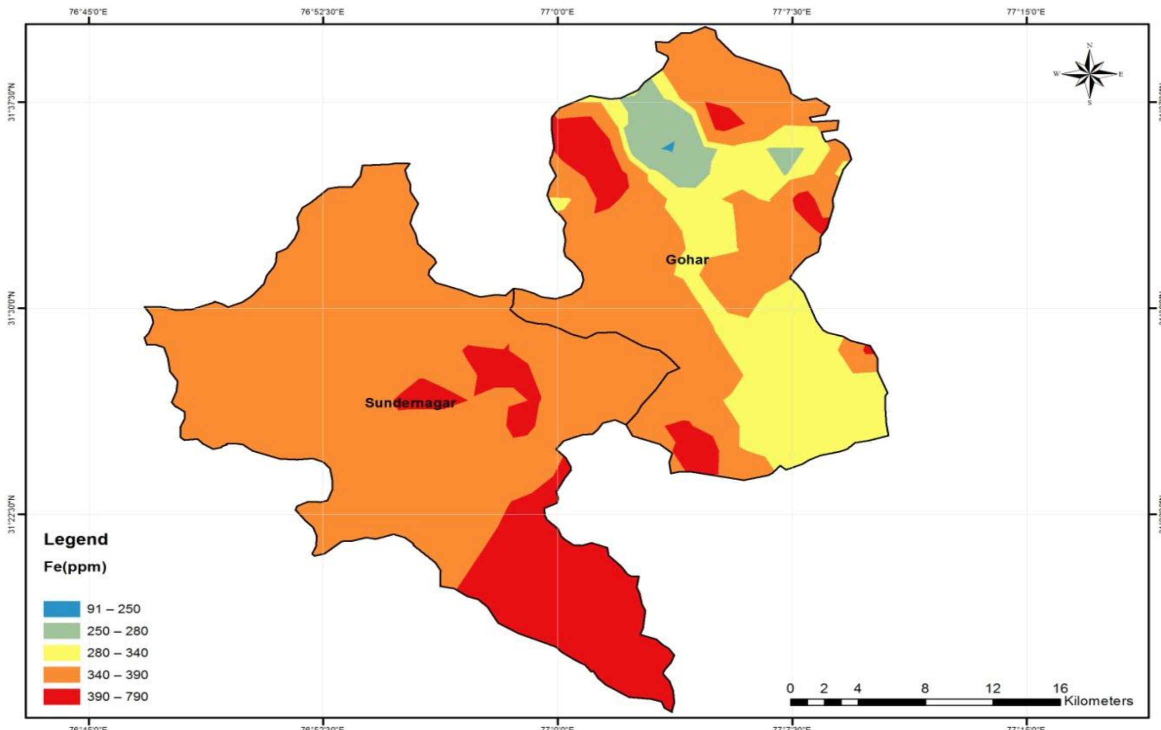

Figure 4.23 Spatial distribution map of leaf iron

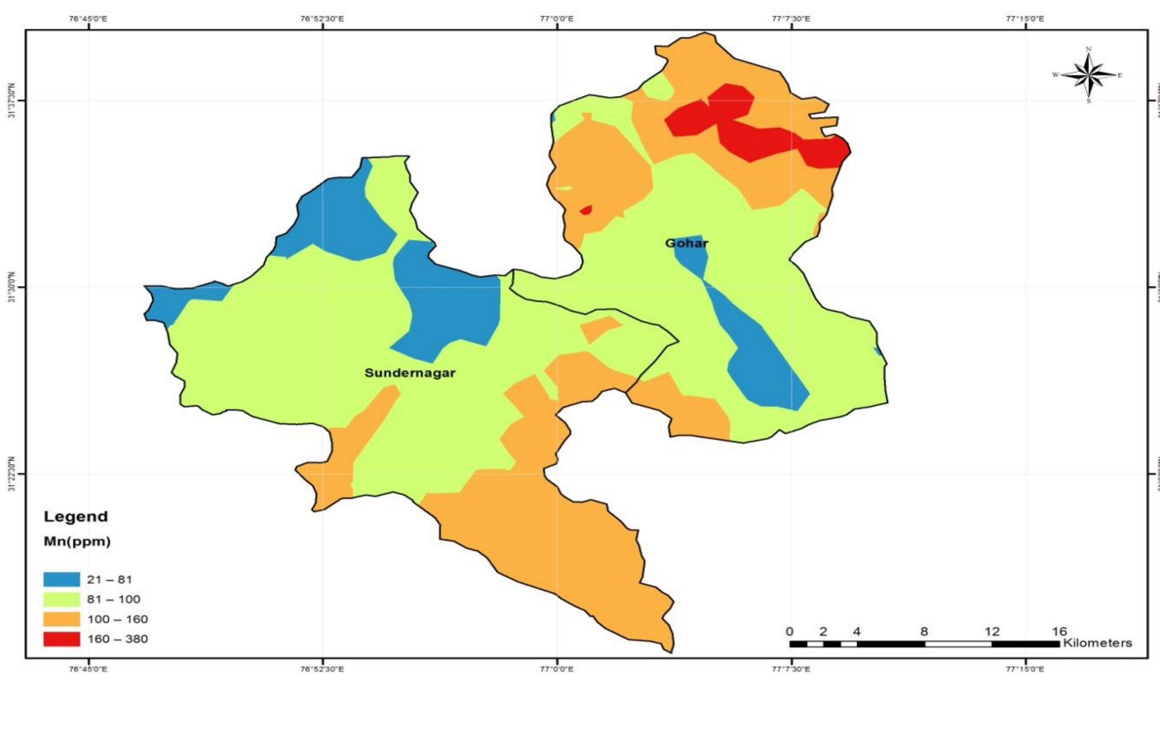

Figure 4.24 Spatial distribution map of leaf manganese

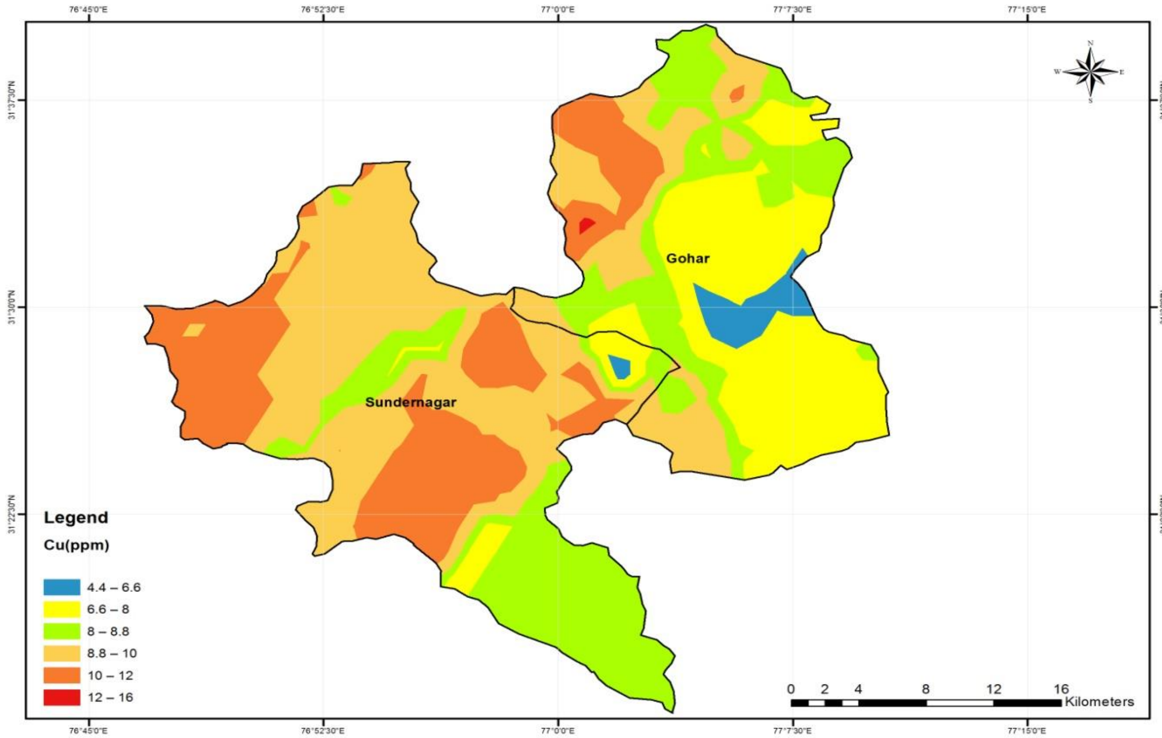

Figure 4.25 Spatial distribution map of leaf copper

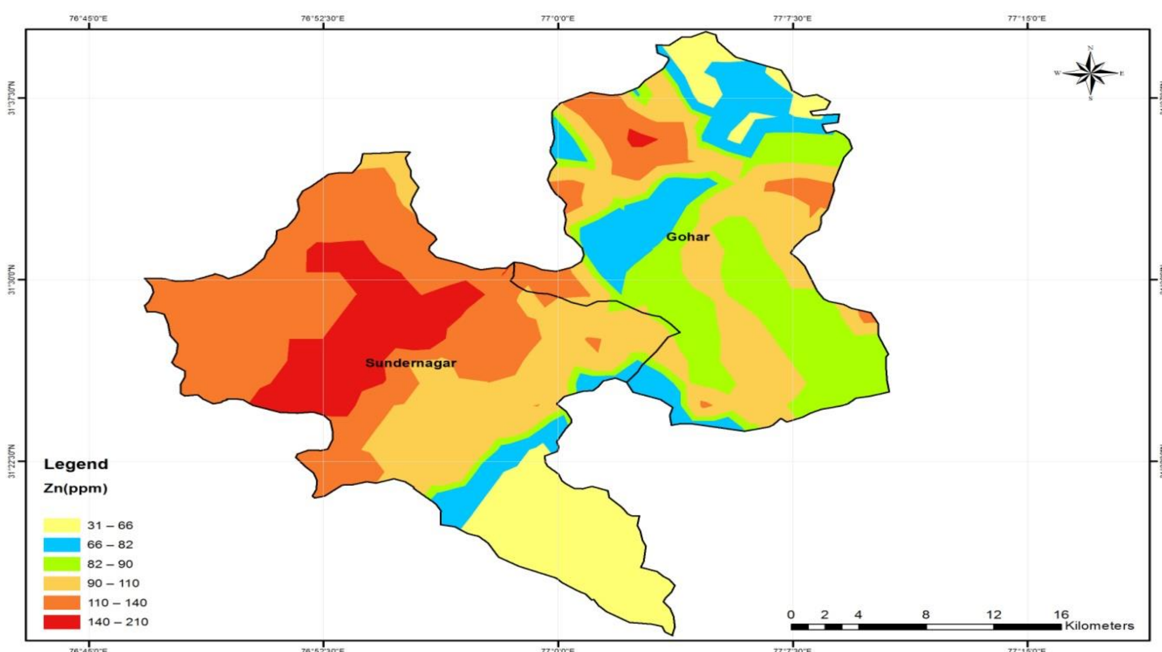

Figure 4.26 Spatial distribution map of leaf zinc

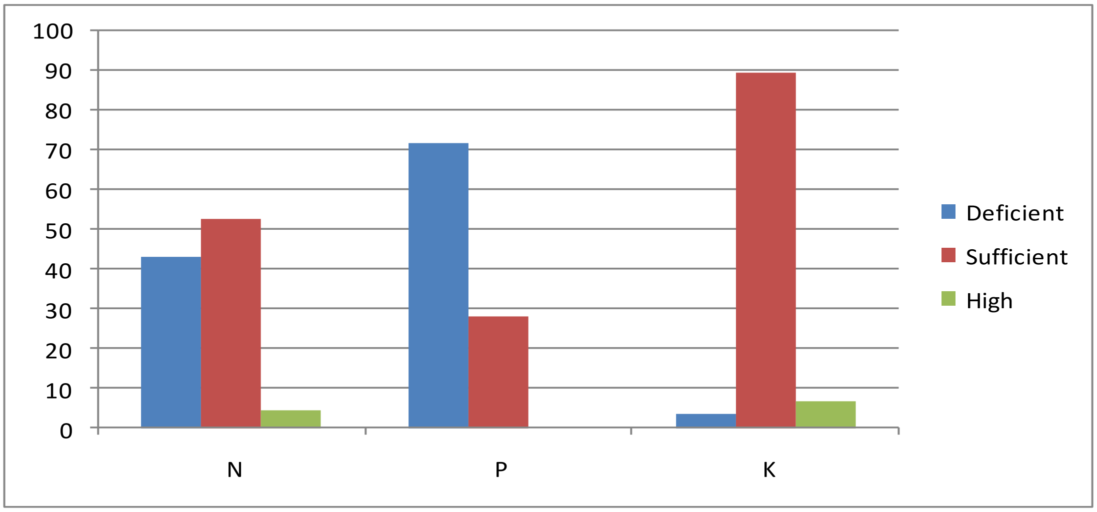

Figure 4.27 Per cent leaf samples in different nutrient ranges for N, P and K

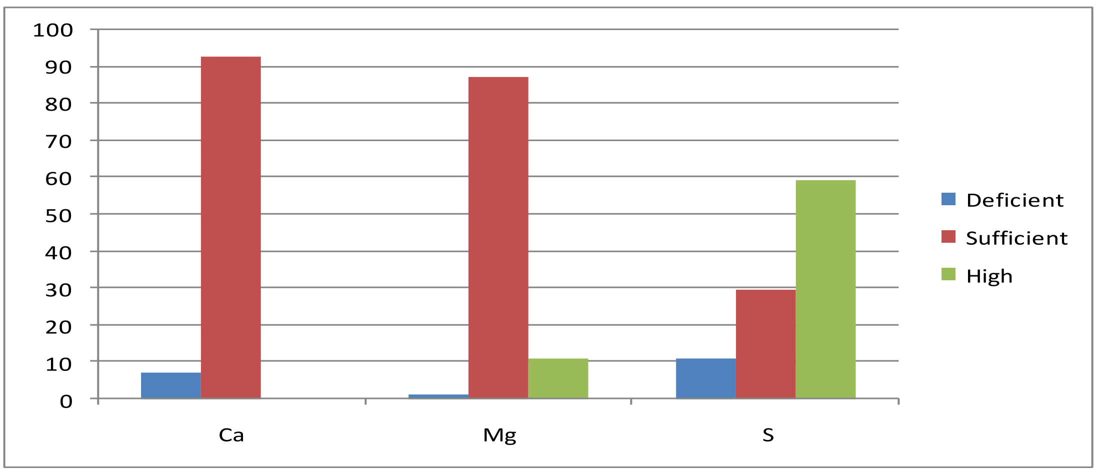

Figure 4.28 Per cent leaf samples in different nutrient ranges for Ca, Mg and S

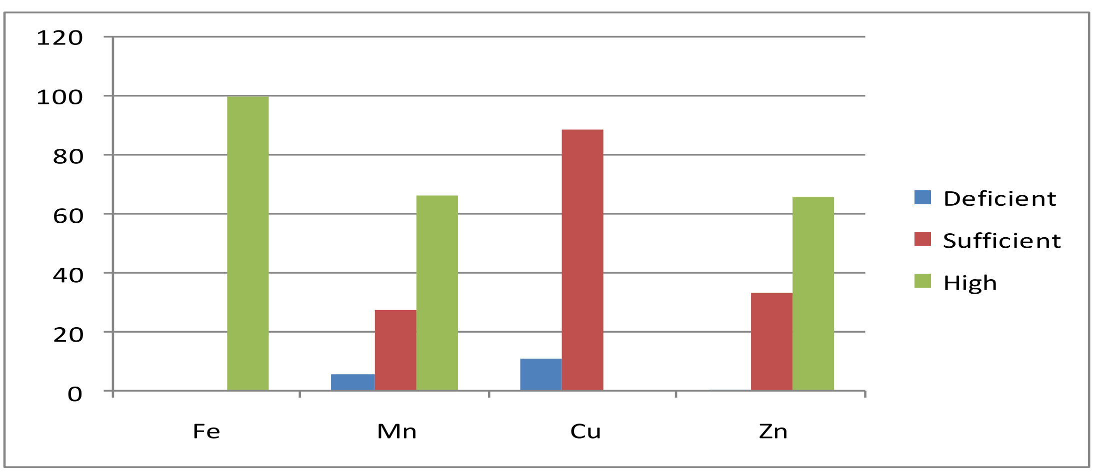

Figure 4.29 Per cent leaf samples in different nutrient ranges for Fe, Mn, Cu and Zn

(r = -0.44**) and DTPA-extractable Cu (r = -0.23**). Organic carbon showed a non-significant and positive correlation with other nutrients.

The perusal of data shows that electrical conductivity was found to be highly significant and positive correlation with available P (r = 0.29**) and DTPA-extractable Cu (r = 0.24**). On the other hand, EC was highly negatively correlated with DTPA-extractable Fe (r = -0.47**) and Mn (r= -0.18*) and available N (r= -0.17*).

Soil pH was highly significantly and positively correlated with EC (r = 0.50**), DTPA-extractable Cu (r = 0.40**) and available P (r= 0.31**). However, pH in the soil was highly significant and negatively correlated with DTPA-extractable Fe (r = -0.52**) and available N (r = -0.46**). Soil pH relationship with all other nutrients was non-significant.

Soil pH is considered as the driver of soil fertility because of its direct impact on nutrient availability and plant growth. Katyal and Aggarwal (1982) have also depicted an inverse relationship of soil pH with available Fe, whereas, Mishra *et al* (1990) observed a positive relationship of soil pH with available P and Cu in foot hill soils of Himalayas. The relationships obtained for electrical conductivity are supported by the findings of Ramana Murthy and Srivastava (1994) who observed a positive and significant correlation of EC with available P. A positive and significant correlation of pH with EC was also observed by Kashiwar *et al.* (2018). The significant and positive correlation between organic carbon and available nitrogen could be because of release of mineralizable nitrogen from soil organic matter in proportionate amounts and adsorption of NH_4 –N by humus complexes in soil. The results are in conformity with those of Patil *et al.* (2015). The availability of Fe increased with the increase in organic matter content because Fe is held in the chelates as soluble complex. The results are supported by the findings of Behera and Shukla (2013) which explain that complexing agents generated by organic matter decomposition promote availability of these nutrients in acid soils of India. Further, the studies of Bhandari and Randhawa (1985) also pointed to a positive correlation of organic carbon with available micronutrient elements in soils of Himachal Pradesh.

Table 4.13 Simple correlation coefficient (r) between different soil characteristics

Soil / Soil	BD	pH	EC	OC	N	P	K	Ca	Mg	S	Fe	Mn	Cu	Zn
BD	1													
pH	0.21*	1												
EC	0.30**	0.50**	1											
OC	-0.02	-0.13	-0.07	1										
N	-0.19*	-0.46**	-0.17*	0.35**	1									
P	0.24**	0.31**	0.29**	0.06	-0.22**	1								
K	0.22**	0.12	0.11	0.07	-0.05	0.13	1							
Ca	0.23**	-0.06	0.08	-0.44**	-0.29**	-0.06	0.23**	1						
Mg	-0.01	0.03	0.04	0.04	-0.13	0.09	0.01	-0.05	1					
S	0.22**	-0.01	-0.08	0.10	0.08	0.14	-0.18*	-0.17*	-0.04	1				
Fe	-0.26**	-0.52**	-0.47**	0.37**	0.40**	-0.33**	-0.36**	-0.29**	-0.03	0.15	1			
Mn	0.02	0.05	-0.18*	0.21*	-0.06	-0.01	-0.30**	-0.22**	-0.02	0.27**	0.55**	1		
Cu	0.24**	0.40**	0.24**	-0.23**	-0.34**	0.18*	-0.19*	0.16	-0.08	0.08	0.06	0.34**	1	
Zn	0.07	-0.02	0.02	0.45**	0.16	-0.01	0.07	-0.15	-0.12	0.13	0.24**	0.33**	0.13	1

*Correlation is significant at the 0.05 level (2-tailed).
**Correlation is significant at the 0.01 level (2-tailed).

4.4.3 Relationship among soil nutrient elements

The available N was positively and highly significantly correlated with DTPA-extractable Fe (r = 0.40**), while it was highly significantly negatively correlated with DTPA- extractable Cu (r = -0.34**), exchangeable Ca (r = -0.29**) and available P (r = -0.22**). Available P content was significantly and positively correlated with DTPA- extractable Cu (r = 0.18*) and highly negatively correlated with DTPA- extractable Fe (r = -0.33**). The available K registered a highly significant and positive correlation with exchangeable Ca (r = 0.23**). On the other hand, it was highly significantly and negative correlation with DTPA- extractable Fe (r = -0.36**) and Mn (r = -0.30**) and significantly negative correlation with DTPA-extractable Cu (r = -0.19*) and available S (r = -0.18*). The exchangeable Ca was highly significantly and negatively correlated with DTPA- extractable Fe (r = -0.29**) and Mn (r = -0.22**) and negatively correlated with available S (r = -0.17*). A negative correlation between exchangeable Ca and DTPA- extractable Fe indicates that with increase in one the other decrease. The available sulphur was highly significant and positively correlated with DTPA- extractable Mn (r = 0.27**). The DTPA- extractable Fe was highly significantly and positively correlated with DTPA- extractable Mn (r = 0.55**) and Zn (r = 0.24**). The DTPA- extractable Mn was highly significant and positively correlated with DTPA- extractable Cu (r = 0.34**) and Zn (r = 0.33**). The results are in agreement with the findings of Katyal and Sharma (1991), Annepu *et al.* (2017), Kashiwar *et al.* (2018), Kakar *et al.* (2018b) and Patel *et al.* (2019). This positive relationship indicates that similar factors influence the distribution of these metals in soil and soils rich in these micronutrients.

4.4.4 Relationship of nutrient elements in plants with soil properties

The perusal of data presented in table 4.14 indicates that the surface soil pH had a highly significantly negative correlation with leaf N (r = -0.23**), Ca (r = -0.22**) and Mn (r = -0.19*). Electrical conductivity (EC) of the soil was found to be highly significant and negatively correlated with leaf N (r = -0.26**). The soil organic carbon was significant and negatively correlated with leaf S (r = -0.20*), Ca (r = -0.19*), Cu (r = -0.19*), Mg (r = -0.18*) and Mn (r = -0.18*). The available N in the soil was highly significant and positively correlated with leaf Mn (r = 0.22**), while it was highly negatively correlated with leaf Mg (r = -0.23**). The P content in the soil was highly significantly and positively correlated with leaf Zn (r = 0.30**), Mg (r = 0.23**) and Cu (r = 0.23**) and positively correlated with leaf K (r = 0.21*). A significant and negative correlation of available K with leaf N (r = -0.25**), with leaf

Table 4.14 Simple correlation coefficient (r) between surface layer soil characteristics and leaf nutrient content

Soil / Leaf	pH	EC	OC	N	P	K	Ca	Mg	S	Fe	Mn	Cu	Zn
N	-0.23**	-0.26**	0.16	0.08	-0.10	-0.25**	-0.23**	0.37**	0.24**	0.27**	0.19*	-0.14	0.09
P	-0.12	-0.09	0.00	0.06	-0.06	-0.21*	-0.05	-0.09	0.22**	0.09	0.05	-0.02	0.07
K	-0.02	-0.01	-0.10	-0.03	0.21*	0.04	0.18*	0.44**	0.04	-0.03	-0.01	0.07	-0.05
Ca	-0.22**	-0.06	-0.19*	-0.02	0.04	-0.17*	0.24**	0.44**	0.08	0.09	0.07	0.10	0.00
Mg	0.00	0.12	-0.18*	-0.23**	0.23**	0.05	0.32**	0.69**	-0.11	-0.23**	-0.12	0.05	-0.12
S	0.05	0.15	-0.20*	0.06	0.13	-0.03	0.20*	0.16	0.04	-0.12	-0.02	0.17*	-0.05
Fe	0.04	0.15	-0.08	-0.09	0.16	-0.01	0.11	0.02	-0.23**	-0.12	0.01	0.19*	0.06
Mn	-0.19*	-0.06	-0.18*	0.22**	-0.15	-0.15	0.04	0.08	0.01	0.07	0.03	-0.01	-0.09
Cu	-0.13	0.04	-0.19*	-0.01	0.23**	-0.11	0.29**	0.23**	0.15	-0.19*	-0.13	0.03	-0.10
Zn	-0.03	0.00	0.00	-0.05	0.30**	-0.10	0.07	0.02	0.22**	-0.03	0.07	0.09	0.11

*Correlation is significant at the 0.05 level (2-tailed).

**Correlation is significant at the 0.01 level (2-tailed).

P (r = -0.21*) and leaf Ca (r = -0.17*) was observed. The Ca uptake by plants may be reduced due to high concentration of soil K. The soil Ca was highly significantly and positively correlated with leaf Mg (r = 0.32**), Cu (r= 0.29**) and Ca (r = 0.24**) and also correlated with leaf S (r = 0.20*) and K (r = 0.18*). While, Ca was highly negatively significantly correlated with leaf N (r = -0.23**) only. The soil Mg was positively correlated with leaf Mg (r = 0.69**), K (r = 0.44**), Ca (r = 0.44**), N (r = 0.37**) and Cu (r = 0.23**). The sulphur in the soil was highly significantly and positively correlated with leaf N (r = 0.24**), P (r = 0.22**) and Zn (r = 0.22**), while it was negatively correlated with leaf Fe (r = -0.23**). The Fe content in the soil was highly positively and significantly correlated with leaf N (r = 0.27**). On the other hand, it was highly significant and negatively correlated with leaf Mg (r = -0.23**) and negatively correlated with Cu (r = -0.19*). A significant and positive correlation was recorded between soil Mn and leaf N (r = 0.19*). The Cu content in the soil was significantly and positively correlated with leaf Fe (r = 0.19*) and S (r = 0.17*). The soil Zn did not showed any significant correlation with any of the leaf nutrient.

The highly positive and significant value of correlation coefficient between leaf nutrient status and soil nutrient status of the surface soils clearly indicates that surface soils (0-15 cm) are contributing more towards the nutrient uptake by the pea crop in the study area.

The data in the Table 4.15 shows that the sub-surface soil pH had a highly significantly and negative correlated with leaf N (r = -0.25**) and had negative correlation with leaf Ca (r = -0.20*) and Mn (r = 0.18*). The electrical conductivity of the soil was found to be significantly and positively correlated with leaf Mg (r = 0.18*), Fe (r = 0.18*) and S (r = 0.17*), while it was highly significantly and negatively correlated with leaf N (r = -0.23**). A highly significant and negative correlation was recorded between soil organic carbon and leaf S (r = -0.23**). The available N in the soil was highly significantly and positively correlated with leaf Mn (r = 0.22**), while it was negatively correlated with leaf Mg (r = -0.19*). The P content in the soil was highly significantly and positively correlated with leaf Zn (r = 0.32**) and positively correlated with leaf Mg (r = 0.21*), Cu (r = 0.21*) and Fe (r = 0.20*). The available K was highly significantly and negatively correlated with leaf P (r = -0.23**) and N (r = -0.22**) and negatively correlated with leaf Mn (r = -0.17*). The soil Ca was highly significantly and positively correlated with leaf Mg (r = 0.36**), S (r = 0.27**) and Cu (r = 0.26**) and positively correlated with leaf Ca (r = 0.18*), Fe (r = 0.18*) and K (r = 0.17*). On the other hand, it was

Table 4.15 Simple correlation analysis (r) between sub-surface layer soil characteristics and leaf nutrient content

Soil / Leaf	pH	EC	OC	N	P	K	Ca	Mg	S	Fe	Mn	Cu	Zn
N	-0.25**	-0.23**	0.11	0.05	-0.16	-0.22**	-0.34**	0.39**	0.22**	0.28**	0.22**	-0.17*	0.10
P	-0.13	-0.06	-0.03	0.02	-0.11	-0.23**	-0.07	-0.06	0.20*	0.08	0.05	-0.02	0.07
K	-0.02	0.04	-0.04	0.01	0.13	-0.06	0.17*	0.37**	0.06	-0.03	-0.04	0.06	-0.07
Ca	-0.20*	-0.03	-0.15	0.05	0.06	-0.12	0.18*	0.41**	-0.03	0.09	0.05	0.08	-0.02
Mg	0.03	0.18*	-0.13	-0.19*	0.21*	0.09	0.36**	0.65**	-0.21*	-0.23**	-0.13	0.03	-0.15
S	0.08	0.17*	-0.23**	-0.03	0.13	-0.16	0.27**	0.16	-0.04	-0.13	-0.07	0.16	-0.08
Fe	0.04	0.18*	-0.05	-0.11	0.20*	0.10	0.18*	0.03	-0.27**	-0.12	-0.07	0.18*	0.05
Mn	-0.18*	-0.04	-0.12	0.22**	-0.11	-0.17*	-0.01	0.05	0.01	0.08	0.05	-0.03	-0.09
Cu	-0.11	0.09	-0.15	-0.01	0.21*	-0.16	0.26**	0.24**	0.09	-0.18*	-0.12	0.02	-0.11
Zn	-0.02	0.03	0.07	-0.02	0.32**	-0.08	0.12	0.03	0.13	-0.04	0.07	0.09	0.09

*Correlation is significant at the 0.05 level (2-tailed).

**Correlation is significant at the 0.01 level (2-tailed).

highly negatively correlated with leaf N (r = -0.34**). The soil Mg was highly significant and positively correlated with leaf Mg (r = 0.65**), Ca (r = 0.41**), N (r = 0.39**), K (r = 0.37**) and Cu (r = 0.24**). The sulphur content in the soil was highly significantly and positively correlated with leaf N (r = 0.22**) and positively correlated with leaf P (r = 0.20*). While, it was highly significant and negatively correlated with leaf Fe (r = -0.27**) and negatively correlated with leaf Mg (r = -0.21*). The soil Fe was highly significantly and positively correlated with leaf N (r = 0.28**). On the other hand, it was highly negatively and significantly correlated with leaf Mg (r = -0.23**) and negatively correlated with leaf Cu (r = -0.18*). A highly positive and significant correlation was observed between soil Mn and leaf N (r = 0.22**). The soil Cu was significant and positively correlated with leaf Fe (r = 0.18*) and negatively correlated with leaf N (r = -0.17*). The Zn content in the soil did not showed any correlation significant with leaf nutrient contents.

Similar correlations between leaf and soil nutrients were also observed by Amuri *et al.* (2017), Sharma *et al.* (2018a) and Mogta and Sharma (2018). Further, Kakar *et al.* (2018a) reported that soil pH had a negative and significant correlation with leaf Mn (r= -0.51**) in Saproon valley of Himachal Pradesh. The available K content in the soil also had a negative and significant correlation with leaf Ca (r= -0.52**).

In the present study correlations were not perfect for some nutrient elements which may probably due to the influence of weather and ion antagonism. The variation in degree of relationship between soil available nutrient elements and plant nutrients may be attributed to diverse soil characteristics including soil pH, temperature, moisture, organic matter, mineral contents and interaction of nutrients with each other that influences the availability of nutrients in soils (Zia *et al.*, 2004). Another reason for poor correlation might be that methods used for soil analysis have not been standardized for vegetable crops of particular area under study and the critical limits used for grouping the analysis data into various classes need modifications, suiting our conditions. The poor correlation between soil and plant tests is not surprising, as poor relation between the two have been reported in many crops by many workers Zia *et al.* (2004), Aziz *et al.* (2004) and Shah and Shahzad (2008). The highly significant correlation indicates that both measurements taken together give more reliable information. So both soil and leaf analysis has to be used for proper diagnostic and prognostic work for determination of nutritional needs of pea growing areas.

SUMMARY AND CONCLUSIONS

Chapter – 5

SUMMARY AND CONCLUSIONS

The present investigation entitled **"Nutritional status of vegetable growing areas of Mandi district of Himachal Pradesh"** was carried out during 2018 in Mandi district of Himachal Pradesh with the objective to evaluate the macro and micro nutrient status of soils of pea growing areas of the district and to work out the relationship among available nutrients and leaf nutrient contents. One hundred thirty five representative soil samples from surface (0-15 cm) and sub-surface (15-30 cm) layers were collected randomly using GPS from forty nine major pea growing villages of Gohar and Sundernagar blocks of the district. Invariably, two-three soil samples were collected generally from each village for surface and sub-surface layers. The pea leaf samples were also collected from the same field from where the soil samples were collected. The collected samples of both soil and plant were analyzed for various properties by adopting standard analytical methods. The results obtained are summarized as below.

5.1 Soil fertility status

5.1.1 Physical properties of soil

5.1.1.1 Soil texture and bulk density

The sand, silt and clay content in 0-15cm soil depth varied from 32.7 to 66.7, 12.0 to 38.3 and 17.2 to 35.3 per cent with mean values 51.3, 25.2 and 23.5 per cent, respectively. The respective values for sub-surface depth were 29.6 to 64.7, 12.2 to 38.5 and 17.8 to 36.3 per cent with mean values of 49.2, 25.9 and 24.9 per cent. A gradual decrease in percentage of sand and increase in percentage of silt and clay was noticed from surface to sub-surface depths. On the basis of soil textural classes the soils of different locations under investigation were silty loam, loam, silty clay loam and clay loam in texture.

Soil bulk density of pea growing area ranged from 1.02 to 1.30 g cm^{-3} and 1.07 to 1.38 g cm^{-3} in surface and sub-surface soils with mean values of 1.18 g cm^{-3} and 1.26 g cm^{-3}, respectively. The bulk density of the surface and sub-surface soil sample is < 1.6 g cm^{-3}, hence the soils are less compact and does not interfere with root growth.

5.1.2 Chemical properties of soil

5.1.2.1 Soil pH, electrical conductivity (EC) and organic carbon (OC)

The pH of the soil ranged from 4.4 to 7.7 (extremely acidic to slightly alkaline) and 4.7 to 7.7 (very strongly acidic to slightly alkaline) with mean values of 6.15 and 6.18 in surface and sub-surface layers of Gohar and Sundernagar blocks. Electrical conductivity indicates that in surface and sub-surface soils, its values ranged from 0.013 to 0.185 and 0.017 to 0.155 dS m^{-1}, with mean values of 0.07 and 0.06 dS m^{-1}. The organic carbon content of the soils varied from 2.6 to 26.9 g kg^{-1} and 3.5 to 24.0 g kg^{-1} with mean values of 13.8 and 11.5 g kg^{-1} in surface and sub-surface layers, respectively. The soils of the study area are medium to high in OC and its content decreases with soil depth.

5.1.2.2 Macronutrient status of soil

The available N content in the study area ranged from 94.1 to 345.0 kg ha^{-1} and 62.7 to 313.6 kg ha^{-1} with mean values of 166.6 kg ha^{-1} and 136.8 kg ha^{-1} in surface and sub-surface soils, respectively. The soils of pea growing area are low in available N content and its availability decreased with the soil depth. The available P content of the pea growing soils ranged from 15.4 to 173.8 and 7.7 to 144.8 kg ha^{-1} with mean values of 93.4 and 64.5 kg ha^{-1}, in the surface and sub-surface soils. It can be inferred that surface soils of Gohar and Sundernagar blocks are high in available P content as compared to sub-surface soils. The available K content ranged from 118.8 to 830.9 and 78.9 to 584.4 kg ha^{-1} with mean values of 335.9 kg ha^{-1} and 219.2 kg ha^{-1} in surface and sub-surface soils, respectively. The soils of pea growing area are high in available K status.

The exchangeable Ca content ranged from 2.99 to 5.91 [cmol (p^+) kg^{-1}] and 2.07 to 5.13 [cmol (p^+) kg^{-1}] with mean values of 4.85 [cmol (p^+) kg^{-1}] and 4.01 [cmol (p^+) kg^{-1}] in surface and sub-surface soils of pea growing area. The exchangeable Mg ranged from 1.92 to 3.89 and 1.72 to 3.60 [cmol (p^+) kg^{-1}] with mean values of 2.76 and 2.62 [cmol (p^+) kg^{-1}] in surface and sub-surface soils of the study area. The soils of the Gohar and Sundernagar blocks are rich in exchangeable Ca and Mg owing to the parent material of the soils. The available sulphur content in the study area ranged from 8.33 to 57.2 mg kg^{-1} and 7.8 to 54.4 mg kg^{-1} with mean values of 41.3 mg kg^{-1} and 34.7 mg kg^{-1} in surface and sub-surface soil, respectively, with overall high status.

5.1.2.3 Micronutrient status of soil

The DTPA-extractable Fe content ranged from 13.3 to 119.9 mg kg^{-1} and 10.7 to 117.6 mg kg^{-1} with mean values of 76.6 mg kg^{-1} and 71.9 mg kg^{-1} in surface and sub-surface soils of pea growing area. The DTPA-extractable Mn content ranged from 2.8 to 41.2 mg kg^{-1} and 2.1 to 38.2 mg kg^{-1} in surface and sub-surface layer with mean values of 32.3 and 29.2 mg kg^{-1}. The DTPA-extractable Cu content ranged from 0.06 to 4.85 mg kg^{-1} and 0.10 to 4.10 mg kg^{-1} with mean values of 1.42 mg kg^{-1} and 1.23 mg kg^{-1} in the surface and sub-surface soils. The DTPA-extractable Zn content varied from 0.04 to 7.05 mg kg^{-1} and 0.03 to 5.85 mg kg^{-1}, with mean values of 2.13 mg kg^{-1} and 1.83 mg kg^{-1} in surface and sub-surface soils, respectively. Like available macronutrient elements, micronutrient elements were also found to decrease with soil depth.

5.2 Nutrient indices of soil

Nutrient indices indicate that soils of pea growing area of the district, as regards the nutrient status are high in available phosphorus (2.97), available potassium (2.47), available sulphur (2.94), exchangeable calcium (3.00), exchangeable magnesium (3.00), DTPA-extractable iron (3.00), manganese (2.99) and copper (2.66). However, with respect to available nitrogen (1.05) and DTPA-extractable zinc (2.00), soils were low and medium in nutrient status, respectively. Being a major plant nutrient element, nitrogen is a critical for growth, development and productivity of the crop. Therefore, the surface soils of pea growing region differed in nutrient status and may respond differentially to fertilizer application.

For sub-surface soils, nutrient index values varied from 1.01 to 3.00. The P (2.84), exchangeable Ca (3.00), exchangeable Mg (3.00), S (2.81), DTPA-Fe (3.00), Mn (2.99) and Cu (2.56) were high in nutrient status and falling in high categories, respectively. However, nutrient indices indicate that sub-surface soil samples were categorized low for available N (1.01), medium for K (2.17) and DTPA-extractable Zn (1.88), respectively.

5.3 Leaf nutrient status

The N, P and K content in the leaves of pea varied from 0.28 to 3.80, 0.11 to 0.32 and 0.10 to 1.66 per cent with mean values of 2.03, 0.20 and 1.06 per cent, respectively. About 42.96 and 71.85 per cent samples is in deficient range for leaf N and P. In case of K majority of the samples are in sufficient range.

The leaf Ca, Mg and S content ranged from 0.13 to 2.1, 0.08 to 0.37 and 0.26 to 0.96 per cent, with mean values of 1.30, 0.24 and 0.71 per cent, respectively. For leaf Ca and Mg about 92.59 and 87.41 per cent samples are in sufficient category and also sufficient to high status for leaf S.

The leaf Fe, Mn, Cu and Zn ranged from 91.4 to 790.2, 21.0 to 380.6, 4.4 to 16.0 and 19.0 to 213.8 ppm with mean values of 318.8, 105.8, 9.4 and 105.0 ppm, respectively. Leaf Mn and Cu status are found to be deficient in 5.93 and 11.11 percent samples, whereas, leaf Fe and Zn status is sufficient in majority of the samples.

5.4 Correlation among the soil characteristics and leaf nutrient status

Organic carbon exhibits positive and significant correlation with the nutrient content (N, Fe, Mn and Zn) of the soil, showing its importance in the availability of the nutrients in soil. However, OC was highly significantly negatively correlated with exchangeable Ca and DTPA-Cu. Electrical conductivity was found to be highly significant and positively correlated with available P and DTPA-Cu but negatively correlated with available N and DTPA- Fe and Mn. The pH was found to be highly significantly positively correlated with EC, available P and DTPA-Cu, whereas, it was negatively correlated with DTPA-Fe and available N. A significant and negative correlation between pH and leaf Mn content shows that micronutrient cations ought to decrease with higher pH. A significant and negative correlation between available K and leaf Ca shows that the Ca uptake by plants may be reduced due to high concentration of soil K. A positive and significant correlation of leaf nutrient status with the nutrient status of surface soils indicates that, surface soil is contributing more towards nutrient uptake by the pea crop.

Conclusions

On the basis of soil textural classification, the different soils of study area belonged to four textural classes viz. silty loam, loam, silty clay loam and clay loam. The soils are less compact and good for the cultivation of vegetable crops. Soil pH was found to be acidic to neutral in reaction, which suits for pea cultivation. The soils are in safe limits of electrical conductivity. Soil organic carbon is medium to high in status irrespective of soil depth. On the basis of nutrient index, 94.81 and 22.22 per cent surface soil samples were low in N and Zn, respectively. Whereas, P, K, Ca, Mg, S, Fe, Cu and Mn, soil status is high in the study area. The leaf nutrient status indicated that 42.96, 71.85, 11.11 and 11.11 per cent samples were deficient in N, P, S and Cu and 89.63, 92.59, 87.41 and 88.89 per cent were sufficient in K, Ca, Mg and

Cu. The organic carbon content was positively correlated with N, Fe, Mn and Zn nutrient contents. On the basis of coefficient of variation, the soil properties such as the bulk density, pH and exchangeable Ca are least variable. Whereas, available nutrients like N, Ca, Mg, Fe, Mn and leaf N, P, K, Ca, Mg, S and Cu are moderately variable. However, electrical conductivity, OC, available P, K, S, Cu, Zn and leaf Fe, Mn and Zn are highly variable. For moderately and highly variable soil parameters, site specific nutrient management strategies should be developed adopted for enhancing the productivity of the crop in the region.

The variation observed between soil and plant analysis indicated a need either to standardize the available nutrient extracting methods or the change in critical limits suiting our conditions. The detailed field and laboratory investigations may be carried out on location specific basis to establish nutrient status. The present investigation though first of its kind is expected to be quite useful for pea growers, researchers and policy makers for formulation of further research and development programmes for increasing crop production and improving quality.

LITERATURE CITED

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A.O.A.C. 1970. Official and tentative methods of analysis. Association of official Analytical Chemists. William Star Wetglad, Washington.

Amara D M K, Patil P L, Kamara A M and Saidu D H. 2017. Assessment of soil fertility status using nutrient index approach. *Academia Journal of Agricultural Research* **5**:28-38.

Amuri N A, Mhoro L, Mwasyika T and Semu E. 2017. Potential of soil fertility management to improve essential mineral nutrient concentrations in vegetables in Dodoma and Kilombera, Tanzania. *Journal of Agricultural Chemistry and Environment* **6**:105-132.

Annepu S K, Shirur M and Sharma V P. 2017. Assessment of soil fertility status of mid Himalayan region, Himachal Pradesh. *Indian Journal of Ecology* **44**:226- 231.

Anonymous. 2017a. Horticulture at Glance. National Horticultural Board Statistical Database, Gurgaon.

Anonymous. 2017b. Cropwise area and production figures under vegetables during the year 2017-18 in regional office distt. Mandi, HP.

Anonymous. 2019. Area and Production of Horticulture Crops: All India. National Horticultural Board Statistical Database, Gurgaon.

Arnold S L, Doran J W, Schepers J and Wienhold B. 2005. Portable probes to measure electrical conductivity and soil quality in the field. *Communications in Soil Science & Plant Analysis* **36**:2271–2287.

Aziz T, Gill M A, Rahmatullah and Sabir M. 2004. Mineral nutrition of fruit trees. **In** : *Proceedings of Symposium on Plant-Nutrition Management for Horticultural Crops under Water-Stress Conditions,* organized by Soil Science Society of Pakistan, Agriculture Research Institute (ARI), Sariab, Quetta, Balochistan, Pakistan. pp. 28-33.

Behera S K and Shukla A K. 2013. Depth-wise distribution of zinc, copper, manganese and iron in acid soils of India and their relationship with some soil properties. *Journal of the Indian Society of Soil Science* **61**:244-252.

Bhandari A R and Randhawa N S. 1985. Distribution of available micronutrients in soil of apple orchards of Himachal Pradesh. *Journal of the Indian Society of Soil Science* **33**:171-175.

Bhandari A R and Tripathi B R. 1979. Soil testing in fertilizer reccomdations. Department of Soil Science, *Technical Bulletin 10*, Department of Agriculture, Himachal Pradesh, Shimla.

Bhargava B S and Raghupati H B. 1993. Analysis of plant materials for macro and micronutrients. **In** H L S Tandon (ed.) *Method of Analysis of Soils, Plants, Waters and Fertilizers*. FDCO, New Delhi. pp.49-82

Biswas D, Raina J N and Das K K. 2017. Nutrient status of soils and carnation (*Dianthus caryophyllus* Linn.) foliage under protected cultivation in the western Himachal Himalaya. *International Journal of Chemical Studies* **5**:636-642.

Bouyoucos G J. 1927. The hydrometer as a new method for the mechanical analysis of soils. *Soil Science* **23**:343-352.

Campbell C R. 2000. Reference sufficiency ranges for plant analysis in the southern region of the United States. *Southern Cooperative Series Bulletin.* pp. 79-80.

Cannel G H, Bingham F T and Garber M T. 1960. Effects of irrigation and phosphorous on vegetative growth and nutrient composition of tomato leaves. *Soil Science* **89**:53-60.

Carr J K and Myers D E. 1984. *Application of the Theory of Regionalized Variables to the Spatial Analysis of LANDSAT data, in the Proceedings of the Ninth Pecora Symposium on Remote Sensing*, 2-4 Oct. IEEE Computer Society Press. pp. 55-61.

Chand M, Benbi D K and Benipal D S. 2006. Fertilizer recommendations based on soil tests for yield targets of mustard and rapeseed and their validations under farmer's field conditions in Punjab. *Journal of the Indian Society of Soil Science* **54**:316-321.

Chandel S, Tripathi D and Kakar R. 2017. Soil health assessment under protected cultivation of vegetable crops in North West Himalayas. *Journal of Environmental Biology* **38:**97-103.

Chander G, Sharma S, Sharma V, Verma S, Sharma S and Verma T S. 2014. Micronutrient cations status in vegetable growing soils of sub-humid and wet-temperate zones of Himachal Pradesh. *Himachal Journal of Agricultural Research* **40**:79-83.

Chaudhari P R, Ahire D V, Ahire V D, Chkravarty M and Maity S. 2013. Soil bulk density as related to soil texture, organic matter content and available total nutrients of Coimbatore soil. *International Journal of Scientific and Research Publications* **3**:1-7.

Chesnin Leon and Yien C H. 1950. Turbidimetric determination of available sulphates. *Soil Science Society of America Proceedings* **15**:149-151.

Chile`s J P and Delfiner P. 1999. Geostatistics: modeling spatial uncertainty. Wiley, New York. pp. 283–287.

Collins J B and Woodcock C E. 1999. Geostatistical estimation of resolution-dependent variance in remotely sensed images Photogramm. *Engineering and Remote Sensing* **65**:41-50.

Devi S G M and Kumar A K S. 2010. Characterization and classification of coffee growing soils of Karnataka. *Journal of the Indian Society of Soil Science* **58**:125-131.

Dhale S A and Prasad J. 2009. Characterization and classification of sweet orange growing soils of Jalna district of Maharashtra. *Journal of the Indian Society of Soil Science* **57**:11-17.

Doneriya B S, Meena R, Meena V S, Meena R S and Dadhich R. 2013. Soil fertility status of vegetable and pulses growing area under Marihan block in Vindhyan region of Mirzapur district. *An Asian Journal of Soil Science* **8**:286-289.

FAI. 1977. *Hand book of fertilizer usage*, 54th ed., The Fertilizer Association of India, New Delhi.

Gangopadhyay S K, Das P K, Mukhopadhyay N, Nath S and Banerjee S K. 1990. Altitude pattern of soil characteristics under forest vegetation in eastern region. *Journal of the Indian Society of Soil Science* **38**:93-99.

Gomez K A and Gomez A A. 1984. Statistical procedure for agricultural research, 2nd Ed. John Wiley and Sons, Inc., New York, USA. 680p.

Grewal J S, Bhumbla D R and Randhawa N S. 1969.Available micronutrient status of Punjab, Haryana and Himachal soils. *Journal of the Indian Society of Soil Science* **17**:27-31.

Gupta R D and Tripathi B R. 1989. Morphological, physico-chemical, mineralogical properties and pedogenesis of some rice growing soils profiles occurring in Kangra district of Himachal Pradesh. *Oryza* **26**:263-272.

Gupta R D and Tripathi B R. 1996. Mineralogy, genesis and classification of soils of North West Himalayas developed on different parent materials and variable topography. *Journal of the Indian Society of Soil Science* **44**:705-711.

Gupta R D and Verma S D. 1992. Characterization and classification of some soils of Kandi belt in Jammu Siwalik hills. *Journal of Indian Society of Soil Science* **40**:809-815.

Gupta R D, Tripathi B R, Kapoor B S and Goswami S C.1981. Mineralogy of sand and clay fractions in some soils of Himachal Pradesh. *Proceedings of Indian National Science Academy* **47A**:685-694.

Hengl T, Heuvelink G B M and Stein A. 2004. A generic framework for spatial prediction of soil variables based on regression-kriging. *Geoderma* **120**:75–93.

Hochmuth G J and Hanlon E A. 1995. Commercial vegetable crop nutrient requirements in Florida. Gainesville (FL): University of Florida Cooperative Extension Service. Special Publication 177p.

Hosea M K, Makmom A A, Zaharin A A, Ainuddin N A, Niashen L, Mohammad B M, Julius B A, Deborah B O and Shamang K J. 2018. Influence of monsoon regime and microclimate on soil respiration in the tropical forests. *Journal of Environmental Science, Toxicology and Food Technology* **12**:63-73.

Jackson M L. 1967. *Soil Chemical Analysis*. Oxford and IBH Publishing House, Bombay. pp 38.

Jackson M L. 1973. *Soil Chemical Analysis*. Prentice Hall of India Pvt. Ltd., New Delhi.

Jalali V K, Talib A R and Takkar P N. 1989. Distribution of micronutrients in some benchmark soils of Kashmir at different altitudes. *Journal of the Indian Society of Soil Science* **37**:465-469.

Jamio W. 2014. Nutritional survey of apple orchards in Kullu district of Himachal Pradesh. M.Sc. Thesis. Department of Soil Science and Water Management. YSP University of Horticulture and Forestry, Solan. 71p.

Kaistha B P and Gupta R D. 1993. Morphology, mineralogy, genesis and classification of soils of the sub-humid temperate high lands of the central Himalayas. *Journal of the Indian Society of Soil Science* **41**:120-124.

Kaistha B P, Sood R D and Kanwar B S. 1990. Distribution of nitrogen in some forest soil profiles of north western Himalayan region. *Journal of the Indian Society of Soil Science* **38**:15-20.

Kakar R, Tripathi D, Chandel S and Sultanpuri A. 2018a. Nutritional status of tomato leaves in north western Himalayas. *Annals of plant and soil research* **20**:187-190.

Kaker R, Tripathi D, Chandel S and Sultanpuri A. 2018b. Distribution of Micronutrient Cations in relation to soil properties in Saproon Valley of Solan District in North Western Himalayas. *Annals of Plant and Soil Research* **20**:143-147.

Kashiwar S R, Nath T, Kumar D, Kundu M C, Dongarwa U R, Rajput B S, Pandey S K and Dongarwa L N. 2018. Evaluation of Soil Fertility Status of Rajiv Gandhi South Campus (Banaras Hindu University), Mirzapur, Uttar Pradesh by Using GIS. *International Journal of Current Microbiology and Applied Science* **7**:3825-3836.

Katyal J C and Aggarwal S C. 1982. Distribution of total and available micro-nutrient cations in some mulberry growing soils of Krishnarajpet, Karnattaka. *Fertilizer News* **27**:66-86.

Katyal J C and Sharma B D. 1991. DTPA-extractable and total Zn, Cu, Mn and Fe in Indian soils and their association with some soil properties. *Geoderma* **49**:165-179.

Kensworthy A L. 1964. *Fruit, nut and plantation crops- A guide for collection of foliar samples for nutrient chemical analysis*. Horticulture Department Memorandum of Michigan State University, East Lansing. 39p.

Khadka D, Lamichhane S, Bhantana P, Anshari A R, Joshi S and Baruwal P. 2018. Soil fertility assessment and mapping of chungbang farm, Pakhribas, Dhankuta, Nepal. *Advances in Plants and Agriculture Research* **8**:219–227.

Khadka D, Lamichhane S, Shrestha S R and Pant B. 2017. Evaluation of soil fertility status of Regional Agricultural Research Station, Tarahara, Sunsari, Nepal. *Eurasian Journal of Soil Science* **6**:295 -306.

Khajuria N. 2010. Impact of industrialization on water quality and soil health in Baddi-Barotiwala-Nalagarh industrial hubs of Himachal Pradesh. Ph D. Thesis, Department of Soil Science, YSP University of Horticulture and Forestry, Solan. 146p.

Kour S and Jalali V K. 2008. Forms of sulphur and their relationship in soils of different agro-climatic zones of Jammu region. *Journal of the Indian Society of Soil Science* **56**: 309-312.

Kumar A, Srivastava L K, Banvasi R and Mishra V N. 2017a. Current status of major nutrients (Av. N, P and K) deficiencies in soils of Koriya district of Chhattisgarh. *Journal of Pharmacognosy and Phytochemistry* **6**:2583-2587.

Kumar P and Verma T S. 2005. Characterization and classification of some rice growing soils of Palam valley of Himachal Pradesh. *Agropedology* **15**:80-85.

Kumar R and Paliyal S S. 2016. Vertical distribution of available macronutrients in relation to physico-chemical properties under different land uses of cold arid soils of Spiti valley in Himachal Pradesh. *The Bioscan* **10**:579-584.

Kumar R, Paliyal S S, Sharma S K and Rana R S. 2017b. Status and distribution of available macronutrients in relation to physicochemical properties under different land uses of cold arid soils of Spiti valley in Himachal Pradesh. *Environment Conservation Journal* **18**:9-86.

Kumar Ravinder and Paliyal S S. 2018. Physical and chemical properties of soils under mid hill humid conditions of North West Himalayas. *Journal of Pharmacognosy and Phytochemistry* **7**:1482-1485.

Kumari K, Gazala N, Singh A and Kumar P. 2017. Studies on boron fractions with different physico-chemical properties of cultivated soils of Himachal Pradesh, India. *International Journal of Current Microbiology and Applied Sciences* **6**:1547-1555.

Kumari M and Tripathi D. 2018. Effect of integrated nutrient management on availability of nutrients, uptake and yield of pea (*Pisum sativum* L.). *International Journal of Chemical Studies* **6**:1054-1057.

Kyandiah R. 2012. Impact of different land uses on runoff and nutrient losses in Ga_3 a microwatershed of Giri river in Solan district of Himachal Pradesh. M.Sc. Thesis. Department of Soil Science and Water Management, YSP University of Horticulture and Forestry, Solan.74p.

Lahiri T and Chakravarti S K. 1989. Characteristics of some soils of Sikkim at various altitudes. *Journal of the Indian Society of Soil Science* **37**:451-454.

Laxminarayan K. 2006. Evaluation of available nitrogen indices for rice in soils of Mizoram. *Journal of the Indian Society of Soil Science* **54**:322-326.

Lindsay W H and Norvell W A. 1978. Development of DTPA soil test for Zn, Fe, Mn and Cu. *Soil Science Society of American Journal* **42**:420-428.

Lombion L G. 1979. Evaluation of magnesium supplying power of the Nigerian Savannah soils. *Soil Plant Nutrition* **25**:477-492.

Loria N, Bhardwaj S K and Ndungu C K. 2016. Impact of cropping systems on soil properties, nutrient availability and their carbon sequestration potential in Shiwalik hills of Himachal Pradesh. *Journal of Applied and Natural Science* **8**:1479–1484.

Mahajan A, Sharma S K, Gupta R D and Sharma R. 2007. Morphological, physical and chemical properties of soils from North West Himalayas. *Bulgarian Journal of Agricultural Science* **13**:607-618.

Mahla H K, Tiwari A and Devdas D. 2014. Evaluations of soil fertility status in red and yellow soil of Navagarh block in Janjgir-Champa district of Chhattisgarh. *International Journal of Agricultural Sciences* **10**:550- 557.

Mahler R L, Saxena M C and Aeschlimann J. 1988. Soil fertility requirement of pea, lentil, chickpea and faba bean, *R. J. Summerfield (ed.). World Crops: Cool Season Food Legumes* 279-289.

Mckenzie N J, Jacquier D J, Isbell R F, Brown K L. 2004. *Australian Soils and Landscapes An Illustrated Compendium.* CSIRO Publishing: Collingwood, Victoria.

Mengel K and Kirkby E A. 1987. Principles of plant nutrition. Panima publishing company: New Delhi, India. 687p.

Merwin H D and Peech M. 1951. Exchangeability of soils potassium in the silt and clay fractions as influenced by the nature of the complimentary exchangeable cations. *Soil Science Society of American Proceedings* **15**:125-128.

Mesfin A. 1998. Nature and management of Ethiopian soils. Alemaya University of Agriculture, Ethiopia. 272p.

Minhas R S, Minhas H K and Verma S D. 1997. Soil characterization in relation to forest vegetation in the wet temperate zone of Himachal Pradesh. *Journal of the Indian Society of Soil Science* **45**:146-151.

Mishra D K, Das R P and Mitra G N. 1990. Forms of sulphur in some soils of Orissa in relation to relevant soil properties. *Journal of the Indian Society of Soil Science* **36**:61-69.

Mogta A and Sharma U. 2018. Nutrient status of soils and capsicum foliage under protected cultivation in some vegetable growing area in Himachal Pradesh. *International Journal of Chemical Studies* **6**:3067-3072.

Mondal A K, Rai A P, Wali P and Kumar M. 2015. Available micronutrient status and their relationship with soil properties of vegetable growing area of Jammu district. *Progressive Horticulture* **47**:96-99.

Najar G R, Akhtar F, Singh S R and Wani J A. 2009. Characterization and classification of some apple growing soils of Kashmir. *Journal of the Indian Society of Soil Science* **57**:81-84.

Narale S H, Gajbhiye B R and Gourkhede P H. 2015. Study of correlation between S fractions with soil properties in soils of Tuljapur tehsil of Osmanabad district. *International Journal of Tropical Agriculture* **33**:2327-2334.

Nazif W, Sajida P and Iftikhar S. 2006. Status of micronutrients in soils of district Bhimber (Azad Jammu and Kashmir). *Journal of Agricultural and Biological Science* **1**:35-38.

Olsen S R, Cole C V, Watanable F S and Dean L A. 1954. Estimation of available posphorous in soil by extraction with sodium bicarbonate. *USDA Circular* **939**:1-19.

Ozbek, S. 1977. *General fruit*. Cukurova University, Ziraat Fakultesi Yayonlaro, 111. **In**: *Text Book* **6**:386.

Pandey S P, Singh R S and Mishra S K. 2000. Availability of phosphorus and sulphur in Inceptisols of central Uttar Pradesh. *Journal of the Indian Society of Soil Science* **48**:118-121.

Pandey V, Gautam P and Singh A P. 2019. Correlation between physical, chemical and biological properties of soil under different land use systems. *International Journal of Chemical Studies* **7**:469-471.

Parker F W, Nelson W L, Winters E and Miles I E. 1951. The broad interpretation and application of soil test information. *Agronomy Journal* **43**:105-112.

Patel A C, Pavaya R P, Patel A K and Patel V R. 2019. Status of micronutrient cations (Zn, Cu, Mn, Fe) in soils and their relationship with soil properties in Sabarkantha district of Gujarat. *International Journal of Pure and Applied Bioscience* **7**:285-291.

Patel J M, Patel M V, Jadav N J and Pavaya R P. 2011. Distribution of different forms of sulphur in soil of Banaskantha district of Gujarat. *An Asian Journal of Soil Science* **6**:11-16.

Pathak H. 2010. Trend of fertility status of Indian soils. *Current Advances in Agricultural Sciences* **2**:10-12.

Patil R B, Saler R S and Gaikwad V B. 2015. Nutritional survey of different vineyards in Nashik district. *Maharashtra Journal of Basic Sciences* **1**:6-12.

Pattison A B, Moody P W, Badcock K A, Smith L J, Armour J A, Rasiah V, Cobon J A, Gulino L M and Mayer R. 2008. Development of key soil health indicators for the Australian banana industry. *Applied Soil Ecology* **40**:155–164.

Pawar Y, Verma L R, Verma P, Joshi H N, More S G and Dabhi J S. 2017. Influences of integrated use of organic and inorganic sources of nutrients on growth, flowering and yield of garden pea (*Pisum sativum* L.) cv. Bonneville. *Legume Research*. **40**:117-124.

Peter K V, Pranab and Hazra. 2012. Hand book of Vegetables. Stadium press LLC. 481p.

Rai A P, Tundup P, Mondal A K, Kumar V, Samanta A, Kumar M, Kumar R and Dwivedi M C. 2018. Cationic micronutrient status of some soils under different cropping system of Kishtwar district (J&K), India. *International Journal of Current Microbiology and Applied Science* **7**:3596-3602.

Raina J N, Sharma J C and Sharma I P. 2007. Manual on methods for physical and chemical analysis of soils. 138p.

Raina J N. 1988. Physico-chemical properties and available micronutrient status of citrus growing soils of Ponta valley in Himachal Pradesh. *Himachal Journal of Agricultural Research* **14**:44-49.

Rajeshwar M, Rao S C, Balaguraviash D and Khan M A A. 2009. Distribution of available micronutirents in soils of Garikapadu of Krishna district of Andhra Pradesh. *Journal of the Indian Society of Soil Science* **57**:210-213.

Rajput P. 2016. Fractions and fixation of phosphorus in vegetable growing soils of Himachal Pradesh. M.Sc. Thesis. Department of Soil Science and Water Management. YSP University of Horticulture and Forestry, Solan. 90p.

Ramamoorthy B and Bajaj J C. 1969. Available nitrogen, phosphorus and potassium status of Indian soils. *Fertilizer News* **14**:25-36.

Ramana Murthy J and Srivastava P. 1994. Soil fertility status in relation to terrace management at Majhera Farm in lower Shivaliks. *Journal of the Indian Society of Soil Science* **42**:150-152.

Ramana, Singh Y V, Jat L K, Meena S K, Singh Lakhapati, Jatav H S and Paul A. 2015. Available macro nutrient status and their relationship with soil physico-chemical properties of Sri Ganganagar district of Rajasthan, India. *Journal of Pure and Applied Microbiology* **9**:2887-2894.

Rattan R K, Datta S P and Katyal J C. 2008. Micronutrient management: research achievements and future challenges. *Indian Journal of Fertilizers* **4**:93-118.

Reynolds W D, Drury C F, Tan C S, Fox C A and Yang X M. 2009. Use of indicators and pore volume function characteristics to quantify soil physical quality. *Geoderma* **152**:252–263.

Sahu G C and Patnaik S N. 1990. Influence of lime and organic matter in pH and ion exchange phenomenon of some Alfisols. *Journal of the Indian Society of Soil Science* **38**:389-393.

Sakal R, Singh A P, Singh B P, Singh R B, Singh S P and Jha S N. 1986. Availability of zinc, iron, copper and manganese in sub Himalayan hill and forest soils as influenced by certain soil properties. *Journal of the Indian Society of Soil Science* **34**:191-193.

Sanchez P A. 1976. Properties and management of soils in the tropics. John Wiley and Sons, Inc., New York, USA. 618p.

Sandhu O P, Jassal H S, Narender, Dhaliwal S S and Rolaniya L K. 2016. Fractionation and distribution of iron in the salt affected soils of Muktsar district of Punjab. *The Bioscan* **10**:33-39.

Sankhyan C G. 1972. Studies on physico-chemical properties of the representative profiles under tomato growing areas of Saproon valley (Himachal Pradesh), M Sc Thesis, Department of Soil Science, College of Agriculture, H.P. University, Shimla, India. 125p.

Sarma V A K, Krishna P and Budihal S L. 1987. *Soil Resource Mapping of Different States in India- A Laboratory Manual*. National Bureau of Soil Survey and Land Use Planning, Nagpur. 49p.

Shah Z and Shahzad K. 2008. Micronutrients status of apple orchards in Swat valley of N.W.F.P. of Pakistan. *Soil and Environment* **27**:123-130.

Sharma P K, Sharma S P and Jain P K. 2001. Nutrient mining in different agro-climatic zones of Himachal Pradesh. *Fertilizer News* **46**:69-73.

Sharma R and Sood K. 2019. Soil fertility appraisal for apple orchards of Himachal Pradesh using GPS and GIS techniques. *Indian Journal of Horticulture* **76**:417-422.

Sharma S, Kaur M and Verma M L. 2018a. Soil fertility and leaf nutrient status of macro-nutrients in mango orchards under Kangra district of Himachal Pradesh. *International Journal of Chemical Studies* **6**:1317-1322.

Sharma R, Sharma V K and Sharma S D. 2018b. Nutritional status of apple orchards in Kinnaur region of Himachal Pradesh. *Indian Journal of Horticulture* **75**:39-47.

Sharma U and Bhandari A R. 1992. Survey of the nutrient status of apple orchards in Himachal Pradesh. *Indian Journal of Horticulture* **49**:234-241.

Sharma V and Kanwar B B. 2010. Copper status and its relation with soil properties in pea growing soils of high hills dry temperate zone of Himachal Pradesh. *Indian Journal of Agricultural Research* **44**:32-37.

Sharma V and Kanwar B B. 2012. Macronutrients availability in pea growing soils of dry temperate zone of Himachal Pradesh. *Agricultural Science Digest* **32**:301–305.

Shekhar C. 2009. Status and distribution of magnesium in acidic soils of North- Western Himalayas. M.Sc. Thesis, Department of Soil Science. CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur, India. 59p.

Singh B and Raman S S. 1982. Distribution of nutrients in soil profile under pines of North East Himalaya. *Journal of the Indian Society of Soil Science* **30**:320-325.

Singh K K, Adarsh A and Kumari A. 2019. Evaluation of soil fertility status in Kanti block under Muzaffarpur district of North Bihar. *International Journal of Chemical Studies* **7**:1375-1379.

Singh K, Bhandari A R and Tomar K P. 1991. Morphology, genesis and classification of some soils of North-West Himalayas. *Journal of the Indian Society of Soil Science* **39**:139-146.

Singh R A. 1980. Soil Physical Analysis, Kalyani Publishers, Ludhiana. 165p.

Singh S and Kumar P. 2012. Soil fertility status of vegetables growing area of Varanasi and pulses growing area of Mirzapur. *Journal of the Indian Society of Soil Science* **60**:233-236.

Singh S N, Latare A M and Singh S K. 2017. Soil Fertility Status of Majhwa Block of Mirzapur District of Eastern UP, India. *International Journal Current Microbiology and Applied Sciences* **6**:2019-2026.

Singh S P, Gupta R A and Singh H N. 2005. Distribution of micronutrient cations in some soils of Kumaon region of Uttaranchal. *Agropedology* **15**:117-119.

Singh V, Sharma Y K, Singh A K and Bordoloi L J. 2013. Sulphur distribution in Inceptisol of Northern India and genotypic differences in sulphur uptake of rice. *African Journal of Agricultural Research* **8**:855-867.

Somasundaram J, Singh R K, Parandiyal A K, Parasd S N. 2009. Micronutrient status of soils under different land use system in Chambal ravines. *Journal of the Indian Society of Soil Science* **57**:307-312.

Stangel P J. 1969. Micronutrients-The “Fertilizer shoe-Nails.” Pt. 7, A Closer Look at Manganese. *Fertilizer Solutions* **13**:38-44.

Subbiah B V and Asija G L. 1956. Rapid method for estimation of available nitrogen in soils. *Current Science* **25**:259-260.

Takkar P N and Nayyar U R. 1981. Preliminary field observations of manganese deficiency in wheat and berseem. *Fertilizer News* **26**:22-23.

Talukdar M C, Basumatary A and Dutta S K. 2009. Status of DTPA-extractable cationic micronutrients in soils under rice and sugarcane ecosystem of Golaghat district in Assam. *Journal of the Indian Society of Soil Science* **57**:313-316.

Tandon H L S. 1989. Secondary and Micronutrient Recommendation for Soils and Crops. A Guide book. Fertilizer Development and Consultation Organization, New Delhi. 22p.

Tandon H L S. 1991. Sulphur Research and Agricultural Production in India. (3rd Edition). The Sulphur Institution , Washington, D. C. 140p.

Tandon H L S. 2009. Methods of analysis of soils, plants, waters, fertilisers and organic manures. Fertiliser Development and Consultation Organisation, New Delhi. 204p.

Thakur J, Kumar P and Mohit. 2018. Studies on conjoint application of nutrient sources and PGPR on growth, yield, quality, and economics of cauliflower (*Brassica oleracea* var. botrytis L.). *Journal of Plant Nutrition* **41**:1862-1867.

Thakur N R and Bhandari A R. 1986. Available nutrient elements status of soils of a temperate vegetable seed producing valley of Himachal Pradesh. *Journal of the Indian Society of Soil Science* **34**:428-430.

Thakur N R. 1979. Nutritional status of cauliflower seed producing area of Himachal Pradesh. M.Sc. Thesis. Department of Soil Science, CSK Himachal Pradesh KrishiVishvadiyalaya, Palampur, India. 63p.

Thakur P C, Rajoo R K and Dwivedi P. 1971. Nutrient indices, fertilizer requirements and recommendation for Mandi soils. *Himachal Journal of Agricultural Research* **1**:61-64.

Tisdale S L, Nelson W L, Beaton J D and Havlin J L. 1995. Soil fertility and fertilizer, 5th Ed. Prentice-Hall of India, New Delhi. 684p.

Tripathi D and Singh K. 1992. Vertical distribution of sulphur in representative soil groups of Himachal Pradesh. *Journal of the Indian Society of Soil Science* **40**:447-553.

Tripathi D, Singh K and Upadhyay G P. 1994. Distribution of micronutrients in some representative soil profiles of Himachal Pradesh. *Journal of the Indian Society of Soil Science* **42**:143-145.

Tripathi D, Upadhyay G P, Bhandari A R and Sharma U. 1992. Potassium distribution in some orchid soils in Mandi district of Himachal Pradesh. *Journal of Potassium Research* **8**:264-267.

Vara Prasad Rao A P, Naidu M Y S, Ramavatharam N and Rama Rao G. 2008. Characterization, classification and evaluation of soils on different landforms in Ramachndrapuram mandal of Chittoor district in Andhra Pradesh for sustainable land use planning. *Journal of the Indian Society of Soil Science* **56**:23-33.

Verma J R and Tripathi D. 2007. Characterization and classification of some soils of mid Shivalik hills in Himachal Pradesh. *Annals of Plant and Soil Research* **9**:58-62.

Verma K S, Shyampura R S and Jain S P. 1990. Characterization of soils under forests of Kashmir valley. *Journal of the Indian Society of Soil Science* **38**:107-115.

Verma S D, Tripathi B R and Kanwar B S. 1985. Soils of Himachal Pradesh and their Management. *Fertilizer Association of India,* New Delhi. pp.149-163.

Vijayakumar R, Arokiaraj A and Martin Deva Prasath P. 2011. Macronutrient and Micronutrients Status in Relation to Soil Characteristics in South- East Coast Plain-riverine Soils of India. *Oriental Journal of Chemistry* **27**:567-571.

Vista S P, Ghimire T B, Rai S, Kutu B and Karna B K. 2019. Assesment of soil fertility status of vegetable super zone, Kaski. *Journal of Pharmacognosy and Phytochemistry* **8**:555-563.

Vogel A I. 1978. Text book of quantitative inorganic analysis. Richard clay, The Chances press Ltd., Britain.

Wadia D N. 1966. Geology of India. SLBS and McMillan and Company. London.

Walia C S and Chamuah G S. 1990. Characterisation, classification and suitability for land use planning of foot hill soils. *Journal of the Indian Society of Soil Science* **38**:286-292.

Walkley A and Black I A. 1934. Examination of the method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science* **37**:29-38.

Warrick A W, Myers D E and Nielsen D R. 1986. Geostatistical methods applied to soil science. In: Klute, A. (Ed.), Methods of Soil Analysis. Part 1—Physical and Mineralogical

Methods, 2nd Edition. Agronomy Monograph No. 9, ASA and SSSA, Madison, WI. pp. 53–82.

Webster R. 1985. Quantitative spatial analysis of soil in the field. *Advances in Soil Science* **3**:1–70.

Zia M S, Aslam M, Cheema N M, Shah A and Laghari H. 2004. Diagnosis of plant nutrient disorder in fruit plants. **In** : *Proceedings of Symposium on Plant-Nutrition Management for Horticultural Crops under Water-Stress Conditions,* organized by SSSP, ARI, Sariab, Quetta, Balochistan, Pakistan. pp. 16-27.

APPENDICES

APPENDIX-I

List of locations for collection of soil and leaf samples from pea growing areas of Gohar and Sundernagar blocks of Mandi district (H. P.)

Sr. No.	Location	Latitude	Longitude	Altitude (m)
1	Majothi (3)	N 31°33'51.8" N 31°33'31.0" N 31°33'53.0"	E 077°04'13.4" E 077°04'14.0" E 077°04'13.9"	1490 1502 1487
2	Bhawanipur (3)	N 31°33'54.4" N 31°33'52.1" N 31°34'04.6"	E 077°04'20.1" E 077°04'03.5" E 077°03'47.3"	1466 1406 1407
3	Kharsi (3)	N 31°34'12.7" N 31°34'11.4" N 31°34'12.0"	E 077°03'33.2" E 077°03'33.8" E 077°03'34.3"	1389 1395 1388
4	Thachi (3)	N 31°34'21.6" N 31°34'19.9" N 31°34'19.0"	E 077°03'16.4" E 077°03'16.1" E 077°03'16.9"	1299 1300 1301
5	Nalahar (3)	N 31°34'56.1" N 31°34'57.0" N 31°34'57.2"	E 077°05'26.8" E 077°05'25.9" E 077°05'25.2"	1456 1446 1441
6	Sheladhar (3)	N 31°35'18.5" N 31°35'18.4" N 31°35'19.2"	E 077°05'34.2" E 077°05'34.0" E 077°05'34.4"	1576 1586 1598
7	Deem (3)	N 31°35'48.1" N 31°35'48.1" N 31°35'48.2"	E 077°05'24.3" E 077°05'23.3" E 077°05'22.8"	1410 1414 1412
8	Bassi (3)	N 31°35'23.7" N 31°35'23.3" N 31°35'22.2"	E 077°05'05.8" E 077°05'06.5" E 077°05'11.9"	1497 1492 1484
9	Duga (2)	N 31°34'58.4" N 31°34'58.9"	E 077°04'18.8" E 077°04'18.4"	1463 1466
10	Kotla (3)	N 31°35'07.9" N 31°35'07.2" N 31°35'07.0"	E 077°03'58.2" E 077°03'58.9" E 077°03'59.1"	1477 1475 1475
11	Bhava (3)	N 31°34'40.7" N 31°34'41.4" N 31°34'41.3"	E 077°03'14.4" E 077°03'13.5" E 077°03'13.8"	1258 1250 1250
12	Daan (3)	N 31°34'40.4" N 31°34'40.7" N 31°34'40.9"	E 077°03'16.2" E 077°03'15.9" E 077°03'16.0"	1270 1271 1275
13	Taneli (3)	N 31°34'39.7" N 31°34'39.4" N 31°34'39.9"	E 077°03'05.9" E 077°03'06.2" E 077°03'05.8"	1227 1228 1230
14	Gohar (3)	N 31°34'38.7" N 31°34'38.8" N 31°34'38.9"	E 077°02'12.3" E 077°02'11.7" E 077°02'10.6"	1258 1262 1266
15	Khayod (3)	N 31°34'20.5" N 31°34'20.6" N 31°34'21.1"	E 077°01'36.9" E 077°01'36.6" E 077°01'35.6"	1288 1289 1294

16	Dari (3)	N 31°34'11.4" N 31°34'10.0" N 31°34'08.9"	E 077°01'04.1" E 077°01'04.4" E 077°01'04.1"	1305 1307 1318
17	Masog (3)	N 31°33'19.6" N 31°33'17.0" N 31°33'17.3"	E 077°01'05.2" E 077°01'04.5" E 077°01'04.8"	1437 1433 1435
18	Chachyot (3)	N 31°33'10.6" N 31°33'12.0" N 31°33'11.4"	E 077°00'54.2" E 077°00'55.7" E 077°00'55.0"	1439 1472 1475
19	Bharjodu (3)	N 31°32'51.9" N 31°32'53.5" N 31°32'57.7"	E 077°01'41.4" E 077°01'41.5" E 077°01'41.3"	1443 1446 1449
20	Kot (3)	N 31°33'06.8" N 31°33'07.4" N 31°33'07.7"	E 077°01'43.3" E 077°01'43.4" E 077°01'43.3"	1427 1423 1424
21	Naugraun (3)	N 31°33'27.0" N 31°33'25.9" N 31°33'25.7"	E 077°00'20.1" E 077°00'20.3" E 077°00'20.5"	1414 1418 1415
22	Saloyi (3)	N 31°33'40.4" N 31°33'40.2" N 31°33'40.6"	E 077°00'13.0" E 077°00'13.9" E 077°00'13.1"	1420 1422 1420
23	Kutwachi (3)	N 31°31'16.3" N 31°31'16.5" N 31°31'16.8"	E 076°59'53.2" E 076°59'52.3" E 076°59'51.0"	1940 1942 1943
24	Kharadhar (3)	N 31°31'31.1" N 31°31'31.9" N 31°31'31.4"	E 077°00'09.0" E 077°00'10.5" E 077°00'11.3"	1983 1996 2000
25	Sakor (4)	N 31°28′35.2″ N 31°28′34.6″ N 31°28′32.3″ N 31°28′40.4″	E 077°01′33.8″ E 077°01′32.4″ E 077°01′30.0″ E 077°01′31.9″	2071 2076 2070 2086
26	Sangli (4)	N 31°28′47.5″ N 31°28′46.6″ N 31°28′46.0″ N 31°28′46.7″	E 077°00′58.3″ E 077°00′59.7″ E 077°0105.4 E 077°01′06.3″	1865 1853 1856 1865
27	Thamadi (3)	N 31°28′34.3″ N 31°28′33.3″ N 31°28′33.0″	E 077°01′14.1″ E 077°01′15.8″ E 077°01′14.2″	1974 1976 1955
28	Chuni (3)	N 31°28′23.1″ N 31°28′22.2″ N 31°28'22.1"	E 077°00′25.5″ E 077°00′25.8″ E 077°00'25.6"	1979 1977 1976
29	Rohanda (3)	N 31°27'39.1" N 31°27'39.5" N 31°27'41.2"	E 077°02'00.9" E 077°02'01.2" E 077°02'02.9"	2100 2100 2109
30	Ghasnu (3)	N 31°27'43.4" N 31°27'43.4" N 31°27'43.0"	E 077°02'09.4" E 077°02'08.5" E 077°02'08.2"	2131 2130 2132
31	Kamand (3)	N 31°25'50.0" N 31°25'50.3" N 31°25'48.4"	E 077°00'46.7" E 077°00'47.5" E 077°00'50.3"	2000 1999 1995

32	Kathel (3)	N 31°27'08.6" N 31°27'08.7" N 31°27'07.8"	E 077°02'41.9" E 077°02'42.4" E 077°02'42.3"	2228 2237 2224
33	Okhal (3)	N 31°27'07.6" N 31°27'06.0" N 31°27'06.2"	E 077°02'20.7" E 077°02'20.3" E 077°02'21.3"	2219 2206 2200
34	Majhar (2)	N 31°27'14.3" N 31°27'14.5"	E 077°02'07.7" E 077°02'08.3"	2205 2214
35	Majhothi (3)	N 31°27'24.6" N 31°27'24.6" N 31°27'24.7"	E 077°01'59.7" E 077°01'59.3" E 077°01'58.7"	2174 2171 2168
36	Rohangalu (3)	N 31°28'02.3" N 31°28'01.9" N 31°28'00.9"	E 077°01'27.0" E 077°01'26.5" E 077°01'27.3"	2052 2051 2052
37	Laag (2)	N 31°29'07.0" N 31°28'54.8"	E 076°54'13.7" E 076°54'55.2"	1144 1202
38	Nalni (2)	N 31°28'52.3" N 31°28'52.7"	E 076°55'30.0" E 076°55'29.8"	1101 1100
39	Dol (2)	N 31°28'34.7" N 31°28'38.3"	E 076°56'22.0" E 076°56'21.9"	1518 1511
40	Dharli (2)	N 31°28'26.3" N 31°28'24.7"	E 076°56'29.3" E 076°56'31.0"	1532 1535
41	Ghurangalu (2)	N 31°29'33.0" N 31°29'32.0"	E 076°57'58.0" E 076°57'56.3"	1321 1330
42	Jai devi (2)	N 31°29'59.9" N 31°30'00.7"	E 076°57'22.2" E 076°57'22.1"	1241 1244
43	Kandyah (3)	N 31°35'13.9" N 31°35'13.3" N 31°35'11.2"	E 076°53'59.8" E 076°53'59.7" E 076°54'00.2"	784 775 776
44	Chatar (3)	N 31°35'06.6" N 31°34'16.8" N 31°34'17.2"	E 076°54'06.4" E 076°54'06.4" E 076°54'06.2"	777 792 792
45	Rada (3)	N 31°34'11.2" N 31°34'01.4" N 31°34'01.4"	E 076°53'00.1" E 076°53'05.8" E 076°53'05.8"	874 824 824
46	Khilra (3)	N 31°33'53.6" N 31°33'42.7" N 31°33'41.6"	E 076°51'56.2" E 076°52'25.9" E 076°52'53.1"	935 893 857
47	Maun (1)	N 31°27′59.0″	E 077°01′11.6″	2045
48	Gullas (1)	N 31°28′06.6″	E 077°00′50.7″	2036
49	Ghiri (1)	N 31°28'41.4"	E 076°59'41.4"	1913

ABSTRACT

Department of Soil Science and Water Management
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Title of the Thesis	**:**	"**Nutritional status of vegetable growing areas of Mandi district of Himachal Pradesh**"
Name of the Student	**:**	Nishant Thakur
Admission Number	**:**	NF-2017-04-M
Major Discipline	**:**	Soil Science
Minor Discipline	**:**	Vegetable Science
Date of Thesis Submission	**:**	
Total Pages of the thesis	**:**	96+ i-iii
Major Advisor	**:**	Dr. Rakesh Sharma

ABSTRACT

The present study was undertaken to evaluate nutritional status of vegetable growing areas of Mandi district. Soil and leaf samples were collected from 49 pea growing villages of Gohar and Sundernagar blocks of Mandi district. The collected soil and leaf samples were analyzed for different soil properties such as soil texture, bulk density, pH, electrical conductivity, soil organic carbon and available N, P, K, Ca, Mg, S, Fe, Mn, Cu and Zn nutrient. The leaf samples were analyzed for nutrient such as N, P, K, Ca, Mg, S, Fe, Mn, Cu and Zn. On the basis of soil textural classes, the soils of different pea growing areas varied from silty loam to clay loam and the bulk density is < 1.6 g cm^{-3}, hence the soils are less compact and do not interfere with root growth. The soils were acidic to neutral in soil reaction. The soils are in safe limits of electrical conductivity as the values were less than 0.8 dS m^{-1}. Soil organic carbon status was found to be medium to high in both layers. The available N content was low in surface and sub-surface layers. The available K, Cu and Zn contents were medium to high in availability, whereas P, Ca, Mg, S, Fe and Mn were high in status. The leaf nutrient status indicated that 42.96, 71.85, 11.11 and 11.11 per cent samples were deficient in N, P, S and Cu, while 89.63, 92.59, 87.41 and 88.89 per cent were sufficient in K, Ca, Mg and Cu. However, nutrient status of leaf Fe, Mn and Zn were high in 100, 66.67 and 65.93 per cent samples. Soil organic carbon was significant and positively correlated with N, Fe, Mn and Zn. Available Ca and Mg exhibited significant and positive relationship with their respective leaf nutrient contents. On the basis of coefficient of variation, the soil properties such as the bulk density, pH and exchangeable Ca are least variable. Whereas, available nutrients like N, Ca, Mg, Fe, Mn and leaf N, P, K, Ca, Mg, S and Cu are moderately variable. However, electrical conductivity, OC, available P, K, S, Cu, Zn and leaf Fe, Mn and Zn are highly variable. For moderately and highly variable soil parameters, site specific nutrient management strategies should be developed and popularized for enhancing the productivity of the crop in the region.

Signature of the Student	**Signature of the Major Advisor**
Name: Nishant Thakur	**Name:** Dr. Rakesh Sharma
Date:	**Date:**

Head of the Department

BRIEF BIO-DATA OF THE STUDENT

Name	**Nishant Thakur**
Father's Name	Sh. Rup Lal Thakur
Mother's Name	Smt. Roshani Thakur
Date of Birth	05 October, 1995
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Academic Qualifications:

Certificate/ degree	**Year**	**School/ College**	**Board/ University**	**Marks (%)**	**Division**
10^{th} Class	2011	D.A.V. Public School, Sundernagar, Mandi (HP)	CBSE	74.1	First
12^{th} Class	2013	D.A.V. Public School, Sundernagar, Mandi (HP)	CBSE	74	First
B.Sc. (Agriculture)	2017	Doon (PG) College of Agriculture Science & Technology, Dehradun (UK)	HNBGU	76.2	First

Scholarship/ Stipend/ Fellowship, any other financial assistance received during the study period : University Stipend

(Nishant Thakur)