ASSESSMENT OF SOIL HEALTH UNDER VEGETABLE CULTIVATION IN SUB-MONTANE AND SUBTROPICAL ZONE OF HIMACHAL PRADESH

Thesis

by

DIXIT
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submitted to

Dr. YASHWANT SINGH PARMAR UNIVERSITY OF HORTICULTURE AND FORESTRY
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in

partial fulfilment of the requirements for the degree

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CERTIFICATE-I

This is to certify that the thesis titled, "Assessment of soil health under vegetable cultivation in sub-montane and subtropical zone of Himachal Pradesh" submitted in partial fulfilment of the requirements for the award of degree of **MASTER OF SCIENCE (AGRICULTURE)** in the discipline of **SOIL SCIENCE** to the Dr. Yashwant Singh Parmar University of Horticulture and Forestry, (Nauni) Solan (HP) – 173 230 is a bonafide research work carried out by **Mr. Dixit** (NF-2019-18-M) son of Mr. Sohan Lal Taneja under my supervision and that no part of this thesis has been submitted for any other degree or diploma.

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

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Date: **Major Advisor**

CERTIFICATE - II

This is to certify that the thesis titled **"Assessment of soil health under vegetable cultivation in sub-montane and subtropical zone of Himachal Pradesh"**, submitted by **Mr. Dixit (NF-2019-18-M)** son of Mr. Sohan Lal Taneja to the Dr. Yashwant Singh Parmar University of Horticulture & Forestry, (Nauni) Solan (HP) – 173 230 India in the partial fulfilment for 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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Needless to say, all errors and omissions are mine.

Place: Neri, Hamirpur

Date: ***(Dixit)***

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ABBREVATIONS USED

Abbreviation	Meaning
%	Per cent
&	And
*	Significant at the 0.05 level
**	Significant at the 0.01 level
+	Plus
-	Minus
<	Less than
>	More than
°C	Degree Celsius
$\mu g\ g^{-1}$	Microgram per gram
AESR	Agro ecological sub region
Al	Aluminum
B	Boron
C	Carbon
Ca	Calcium
$CaCO_3$	Calcium carbonate
CEC	Cation exchange capacity
CS	Critical scoring
c mol (p^+) kg^{-1}	Centi mol proton per kilogram
cm	Centi metre
Cu	Copper
CV	Coefficient of variance
dS m^{-1}	deci Siemens per metre
DTPA	Diethylene Triamine Penta Acetic Acid
$\mu S\ cm^{-1}$	Micro siemens per centimetre
EC	Electrical conductivity
EDTA	Ethylenediamine tetraacetic acid
et al.	Et alii (and other)
Fig.	Figure
Fe	Iron
FYM	Farm Yard Manure
g	Gram
g cm^{-3}	Gram per centimeter cube
g kg^{-1}	gram per kilogram
ha	Hectare
i.e.	id est (that is)
K	Potassium
kg	Kilogram
kg ha^{-1}	Kilogram per hectare
km^2	Square kilometer
l	Loam
ls	Loamy sand
LS	Linear scoring
m	Metre
MBC	Microbial biomass carbon
MBN	Microbial biomass nitrogen
MDS	Minimum data set

Mn	Manganese
mm	Millimeter
m^2	Square metre
mg kg^{-1}	Milli gram per kilogram
Meq $100g^{-1}$	Milliequivalent per hundred gram
Mg	Magnesium
mg $100g^{-1}$	Milli gram per hundred gram
mg kg^{-1}	Milligram per kilogram
Mg m^{-3}	Mega gram per meter cube
MWHC	Maximum water holding capacity
OC	Organic carbon
P	Phosphorous
POC	Particulate organic carbon
PC	Principal component
PCA	Principal component analysis
pH	Power of hydrogen ions
ppm	Parts per million
RSQI	Relative soil quality index
S	Sulphur
SOM	Soil organic matter
SR	Soil respiration
SQI	Soil quality index
SHI	Soil heath index
sl	Sandy loam
TEA	Triethanolamine
Viz.,	Namely

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Chapter-1

INTRODUCTION

Soil health status is the basis of productivity and sustainability of the production system in agriculture. It deals with the integration and optimization of the physical, chemical and biological properties of the soil for improved productivity and environmental quality and is defined as “the capacity of specific kind of soil to function as a vital living system, within the ecosystem and land-use boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality and promote plant and animal health” (Doran and Zeiss, 2000). Soil health includes dynamic characters of soil and is used to assess the ability of the soil to sustain productivity of plant and maintain or improve water and air quality and support human health. Since all agricultural activities are directly or indirectly affected by how the “soil is handled”, soil health becomes a top priority. Any agricultural system's productivity and sustainability not only depend upon the management practices but also on the environment and the soil quality. Agricultural soil with good quality promotes and sustains good agricultural productivity with less environmental impact and possesses utmost physical, chemical and biological attributes to fulfil these requirements (Reynolds *et al.* 2009). A healthy soil ensures proper water and nutrient retention, release, promotes and sustains root growth, maintains soil biotic habitat, responds to management and resists degradation.

To assess soil health, we need to consider a variety of physical, chemical and biological attributes known as indicators. According to Masto *et al.* (2007), the soil quality concept provides a tool for quantifying the combined biological, chemical and physical response of soil to crop management practises. Many indicators have been developed for ecological and environmental analysis, such as nutrient loss potential on fields (Lemunyon and Gilbert, 1993) and the environmental impacts of different land use mosaics. These indicators could be used to track the soil itself or the results that are influenced by it. Monitoring changes in individual soil health indicators to interpret soil health may not provide complete information about soil health. Integrated soil health indices based on a combination of soil properties provide a better indication of soil health than individual parameters. The indicators used or selected in different regions may differ because soil quality assessment is purpose and site-specific (Wang and Gong 1998; Shukla *et al*. 2006). To assess management-induced changes in soil quality over time, a minimum number of soil quality indicators i.e. minimum data set (MDS) should be identified from a large data set.

Moreover, combining these indicators in a meaningful way into a single index may aid in more precise soil health assessment (Jaenicke and Lengnick 1999; Bucher 2002). The recent approach in assessing soil health includes normalising measured data and converting it to a numeric value that is more than a static descriptor, known as 'soil health index' (SHI). Assessment of soil health comprises three main steps (1) Selection, measurement and minimization of the set of relevant soil attributes (2) Quantification of the selected soil attributes through direct measurement and assigning an appropriate score (3) Integration among the scored attributes to construct the final index by providing criteria for defining the weight of each attribute or group of attributes. A valid soil health index would also aid in the interpretation of data from various soil measurements, indicating whether management and land use are producing the desired results in terms of productivity, environmental protection and health.

Vegetables play an important role in Indian agriculture because they provide food, nutrition, economic security and most importantly higher returns per unit area and time. Furthermore, vegetables have a shorter maturity cycle, a higher value and provide higher income resulting in a better farmer's livelihood. India is the world's second largest producer of vegetables trailing only China and produces 18.88 million tonnes of vegetables from an area of 10.10 million ha (Anonymous, 2019) which is far less than the actual requirement for providing a balanced diet to every individual. To meet the needs of India's growing population, total vegetable production in India must increase to at least 250 million tonnes by 2024-25.

Himachal Pradesh has a considerable potential for vegetable production due to rich biodiversity and varied agro climatic conditions which are highly suitable for growing vegetable crops round the year. Area under vegetable production in Himachal Pradesh is 87.31 thousand ha and production is 1755.43 thousand metric tonnes (Anonymous, 2019). Though, area under vegetable cultivation in state is low but it has shown increasing trend in last few decades. Vegetable growers are showing interest in high yielding varieties. Most of the vegetable crops require higher doses of nutrients and thus resulting in higher removal of nutrients in harvested crop then quantity added *i.e.*, exhaustive mining of nutrients from the soil and ultimately in deterioration of soil health. Chemical fertilizers if used in an unbalanced manner increase the quantity of food produced while decreasing its nutritional quality and soil fertility over time (Sinha *et al*., 2010). Consequently, an increase in vegetable production may have serious negative impacts on soil health and ecosystem services. In Himachal Pradesh, where vegetable farming is intensive, it is essential to analyse the influence of current management techniques such as fertiliser use and other inputs on soil health in order to ensure sustainable long-term production. The changes in soil health reveal, whether the management practices being adopted are sustainable or not.

These all have sparkled interest in the concept of soil health and its assessment. An understanding of soil health and its management strategies is crucial for sustaining production and minimum data set approach has been advocated by many researchers to access the soil health status (Larson and Pierce 1991; Arshad and Coen 1992; Clune *et al.* 2016). However, very few studies have been carried out in vegetable growing areas of Himachal Pradesh. With this background in mind the present study entitled "Assessment of soil health under vegetable cultivation in sub-montane and subtropical zone of Himachal Pradesh" was planned with the following objectives:

1. To assess the effect of vegetable cultivation on soil health
2. To determine the correlation among soil properties and crop productivity

Chapter-2

REVIEW OF LITERATURE

The literature pertaining to the present investigation **"Assessment of soil health under vegetable cultivation in sub-montane and subtropical zone of Himachal Pradesh"** has been reviewed in this chapter and the germane literature has been present under the following heads:

2.1 Assessment of soil health

2.2 Status of soil health indicators

2.2.1 Physical indicators

2.2.2 Chemical indicators

2.2.3 Biological indicators

2.3 Effect of vegetable cultivation on soil properties

2.4 Relationship among soil properties and crop productivity

2.4.1 Relationship among soil properties

2.4.2 Relationship between soil properties and crop productivity

2.1 Assessment of soil health

Soil quality evaluation is vital for determining the best management practises to be used for long-term crop production. The assessment of soil quality is how well soil performs all of its functions. Soil quality cannot be determined solely through measuring crop yield, water quality or any other outcome. Soil, as we know, has chemical, biological and physical properties that interact quickly to give soil its ability to function or perform (Bunemanna *et al*., 2018). Thus, soil capacity cannot be measured directly but must be inferred from changes in its attributes or attributes of the ecosystem which are referred to as indicators. Indicators are collection of measurable attributes derived from functional relationships that can be measured through field observations, field sampling, remote sensing, surveys or the compilation of existing data.

Continuous cultivation for centuries, adoption of modern agricultural technologies and imbalanced fertiliser use combined with inadequate and irregular application of organic manures has resulted in soil nutrient depletion and thus poor fertility of Indian soils

(Malewar, 2005). As a result, a balanced supply of each nutrient in relation to plant growth is essential for achieving normal yield and produce quality.

The goal of soil quality assessment is to monitor changes, compare soils and/or evaluate management effectiveness. Andrews and Carroll (2001) proposed that dynamic soil quality assessment should be viewed as one of the components required to quantify agro-ecosystem sustainability in order to fully appreciate its value.

Soil quality protection in the face of intensive land use and rapid economic development is a major challenge for the developing world's sustainable resource use (Doran *et al.,* 1996). The basic assessment of soil health and soil quality is required to evaluate the state of degradation and changing trends as a result of various land use and small-holder management interventions (Lal, 1995). In Asia, nutrient imbalances in soil, excessive fertilisation, soil pollution and soil loss processes all have negative effects on soil health and quality (Zhang *et al.,* 2006).

Indicators, calculated values or estimated statistics relative to a threshold level are increasingly being used to assess the current state or trend of soil health across biological, environmental, economic, social, institutional and political disciplines (Dalal *et al.*, 2003). To assess soil quality, we need to consider a variety of physical, chemical and biological attributes known as indicators. Soil-quality indicators are valuable tools and are finding increasing application and the focus on biological approaches must not diminish appreciation of the physical and chemical factors in order to develop a productive integration of the three sets of factors.

Many researchers have analysed soil quality using various indicators but only a few have used the results to develop a soil quality index. There is no universal formula for measuring soil quality and it is important to not confuse an index with the methods used to establish it, which tend to be based on the works of Karlen and Stott (1994) and Andrews *et al.* (2002). Although the methods exist, indices are never used on a larger scale or even in similar climatological, agronomic etc. conditions.

The importance of the minimum data set approach was highlighted by Larson and Pierce (1994) for assessing soil health and they suggested aggregate size/stability, bulk density, rooting depth, water holding capacity, texture, available nutrients, pH and total or labile carbon (biological) as indicators for assessing health status of soils under different production systems.

Brookes (1995) agreed on the use of microbial biomass carbon as an indicator of soil health owing to its high sensitivity to changes in land use and management practices.

Kennedy and Pappendick (1995) listed aggregate size/stability, bulk density, rooting depth, water holding capacity (physical measurements) nitrogen and other nutrients, pH, electrical conductivity or salinity, organic matter (chemical measurements) and soil respiration/ dehydrogenase activity, microbial biomass carbon (biological measurements) as main soil attributes/ minimum data set for assessing soil health status.

Doran *et al*. (1996) made use of bulk density, penetration resistance, water holding capacity, infiltration, hydraulic conductivity, water content, water-filled pore space (physical); nitrogen, pH, electrical conductivity or salinity (chemical) for assessing soil health status in arable lands.

Pankhurst *et al*. (1997) reported that the biological indicators had the potential to integrate changes in soil health at the same time reflecting changes in the physical, chemical and biological characteristics of the soil.

Doran and Zeiss (2000) reported that the soil organisms were highly sensitive to land management practice and climate and were well correlated with beneficial soil and ecosystem functions. They highlighted the importance and utility of soil organisms as an indicator/determinant of soil health.

Murage *et al*. (2000) conducted a study to identify indicators of soil fertility status that are consistent with farmers perceptions of soil fertility. They measured physical, chemical and biological properties of soils from paired fields identified as either productive or non- productive by taking 12 farmers. They found that all farmers attributed low fertility to inadequate use of organic and inorganic fertilizers (100%) and removal of crop residues (100%), continuous cropping (83%), lack of crop rotation (66%) and soil erosion (42%). They further reported that productive soils had significantly higher soil pH, effective cation exchange capacity and exchangeable cations, extractable P and total N and P than non-productive soils. Total organic C and several estimates of soil labile C including particulate organic C (POC), $KMnO_4$-oxidizable C and microbial biomass C were significantly greater in productive soils. Soil microbial biomass N, net N mineralization and soil respiration were also significantly higher in productive soils.

According to Andrews *et al.* (2002), decision tools that assist in identifying the most sustainable management practises may benefit consultants, farm advisors, resource conservationists and other land managers. Soil quality indices (SQIs) can provide this service as a data reduction technique, expert opinion (EO) or principal components analysis (PCA) were used to select the smallest data set components.

Karlen *et al*. (2003) reported that the indicator scoring can be accomplished in a variety of ways (linear or nonlinear, optimum, more is better, more is worse) depending upon the function. For some management goals the same indicator may be included under different functions and even scored in different ways. The unitless values were combined into an overall index of soil health and can be used to compare effects of different practices on similar soils or temporal trends on the same soil.

Sicardi *et al.* (2004) reported that the soil microbial biomass was the living part of the soil organic matter formed by fungi, bacteria, protozoa and algae and represents an important source of nutrients that may supply plant demands. Therefore, it was one of the main biological attribute used in soil health studies.

Rezaei *et al*. (2006) used a general approach for choosing the most representative indicators from large existing data sets to develop a method for the selection of suitable predictive indicators to assess the soil health for mountainous rangeland in Northern Iran. They reported that the relationships between soil properties and plant growth showed that plant variables were more sensitive to soil physical properties than to soil chemical properties.

Amacher *et al.* (2007) measured a variety of soil chemical and physical properties in order to answer specific questions about soil quality or health. They created the soil quality index (SQI), a new index for assessing forest soil health that combines 19 measured physical and chemical properties of forest soils into a single number that serves as the soil's "vital sign" of overall soil quality. The SQI is a new tool for establishing baselines and detecting forest health trends.

Kinyangi (2007) proposed that soil health assessment includes a series of actions, such as (1) the selection of soil health indicators (2) the determination of a minimum data set (3) the development of an indices interpretation scheme (4) on-farm assessment and validation. While the use of integrative soil health tests is increasing (Gugino *et al.*, 2009), there is little information available to assess the suitability of soil health indicators for monitoring soil functions in the context of climate change.

Idowu *et al.* (2008) selected a set of parameters to characterize the soil health among 39 physical, chemical and biological attributes and correlated them with plant growth and yield in soils under different tillage, rotation and cover cropping, in commercial production fields of USA. These authors concluded that the most important chemical parameters to be assessed were pH, available phosphorus, potassium, copper, iron, manganese and zinc.

Dhaliwal *et al.* (2009) evaluated the soil quality and yield trends of different crops in low productive sub-montaneous tract and highly productive area in Punjab, India. Among the four land use systems *viz.* cultivated land use system, undisturbed land use system, pasture land use system and forest land use system, the soils in the cultivated land use system of the Kandi area were found better in quality with respect to chemical and physical parameters and were more sustainable as compared to remaining three land use systems. Pasture and undisturbed land use systems exhibited poor soil quality and thus were not suitable for growing agricultural crops.

Kelly *et al.* (2009) found that the chemical attributes of soil health were correlated with the capacity to provide nutrients for plants and/or retaining chemical elements or compounds harmful to the environment and plant growth. Soil pH, cation exchange capacity, soil organic matter and nutrient levels were the main chemical attributes used in soil health assessment, especially when the soil capacity for supporting high yield crops was considered.

Watts *et al.* (2010) reported that the dehydrogenase activity reflect the total range of oxidative activity of soil microflora and consequently may be associated to be a good indicator of microbiological activity.

Sun *et al.* (2011) studied the effects of greenhouse vegetable cultivation on soil's physical quality. Solar greenhouse vegetable cultivation had greater effects on the bulk density of 0-30 cm soil layer. In 0-40 cm solar greenhouse soil profile, the content of clay was lower in upper layer than in deeper layer, indicating their downward movement and this phenomenon was more obvious with increasing year of greenhouse vegetable cultivation. Within the first 5 years of solar greenhouse vegetable cultivation, soil field water capacity decreased significantly with a decrement of 13.8 per cent but remained relatively stable after then.

Kundu *et al.* (2012) conducted a study to assess the soil quality of AESR 10.1 covering largely *Vertisols* using 15 physical, chemical and biological attributes. The relative soil quality index (RSQI) was computed for each district based on 15 attributes which are known to exert significant influence on crop productivity. The soil with RSQI values less than 50 per cent were rated as poor, 50-70 per cent as medium and more than 70 per cent as good quality soils. The RSQI values were significantly correlated with average relative yield (r=0.0636**) indicating the reliability of the proposed method of soil quality assessment.

According to Juan *et al.* (2013), the majority of the farmland soil on Chongming Island was in poor health, accounting for forty nine per cent of the surveyed samples. The very poor health of soil was accounted for nineteen per cent of the surveyed samples, which were distributed in small pieces across Chongming Island's North Western and Eastern regions. Soil pH, organic carbon, biomass carbon and bulk density had less of an impact on soil health, whereas NO^{3-} N, EC and available phosphorous varied greatly. Soil salinization and nitrate accumulation in greenhouse, cropping patterns as well as phosphate fertiliser shortages in paddy fields affected soil health

Quantitative assessment of soil quality to determine the sustainability of land uses in terms of environmental quality and plant productivity was done by Singh *et al*. (2014). The results revealed that organic carbon content and soil acidity components are the major governing factors of soil quality in the prevailing land use types of the region. While SOC and available P tend to increase the soil quality, exchangeable Al and DTPA extractable Mn depreciate it due to their toxic levels in the acidic soils of the study area (important for crop production function of the soil).

Rattan *et al.* (2015) reported that the physical indicators of soil health (pore size distribution, water stable aggregates and bulk density) reflect the capacity to accept, store, transmit and supply water, oxygen and nutrients within ecosystem. Among biological indicators, dehydrogenase was a potential indicator of active soil microbial biomass.

Kalu *et al.* (2015) reported that the soil health management helps to maintain biological productivity, air and water quality and human habitation and health in the Panchase area of Western Nepal. The minimum data set selected by them includes soil pH, bulk density, available phosphorus, soil organic carbon, available potassium and water field pore space. The proper application of fertilizer and giving priority to organic farming is recommended to improve soil health.

Clune *et al.* (2016) studied the Cornell’s comprehensive assessment of soil health protocol and advocated the integration of soil biological, physical and chemical measurements which include soil texture, water holding capacity, wet aggregate stability, organic matter content, microbial respiration and microbial biomass carbon. Overall health score was computed by averaging the individual indicator ratings to provide an indication of the soil’s overall health status.

Raiesi (2017) revealed that the soil organic carbon, electrical conductivity and aryl sulphatase activity were found to be the key health indicators of cultivated soils of Iran.

Bilgili *et al.* (2017) assessed the quality of the Harran Plain soils under long-term cultivation and revealed that the overall soil qualities were generally low (30 < SQI < 70) for the Harran Plain mostly due to low amounts of SOM that were native in the semi-arid climate and presumably also as a result of intensive cropping systems (cotton or wheat-corn). The most useful soil quality parameters included in MDS for monitoring SQ were soil organic matter, microbial biomass, catalase enzyme activity, hydraulic conductivity, bulk density and exchangeable K.

Biswas *et al.* (2017) studied the impact of intensive cultivation on soil health under polyhouses located in Bilaspur, Solan and Sirmaur districts of Himachal Pradesh and revealed that in the light of the soil health index values 36.7, 46.7 and 16.6 per cent of samples were categorized under very high, high and medium soil health, respectively under polyhouse conditions. Such values for open field condition were noted to be 10, 70 and 20 per cent, respectively. They further reported that soil health was found to be affected by the management practices adopted by the farmers and the degree of manure and fertilizer usage over a period of time considerably.

Chandel *et al.* (2018) in their study on soil quality assessment through minimum data set under different land uses of submontane Punjab found that the SQI obtained through LS and CS under the land use was maximum under forest *i.e.,* 0.80 and 0.61 followed by grasses 0.79 and 0.56, horticulture 0.78 and 0.54, cultivated 0.75 and 0.50 and bare 0.67 and 0.46, respectively and the results clearly indicated that SQI under forest, horticulture, grasses and cultivated land use were at par with each other and significantly different under bare land use. The better SQI under the forest land use is attributed to the high soil organic matter status. The minimum data set selected for soil health included soil organic carbon, available potassium, electrical conductivity, plant available water, clay and erodibility factor.

While assessing the soil fertility under different land use systems in Dhading District of Nepal (Kharal *et al.,* 2018) indicated that the land under traditional mixed cereal-based farming systems had poor soil health compared with adjacent vegetable, grazing and forest lands among the study area. The variations in soil fertility parameters suggested the immediate need for improvement in soil health of traditional farmlands.

2.2 Status of soil health indicators

Soil health/quality integrates physical, chemical and biological components, processes and the interactions among them (Karlen *et al*., 2001). The physical properties of soils determine their adaptability to cultivation as well as the level of biological activity that the soil can support and play a significant role in determining the soil's ability to supply water and oxygen to plants. Chemical properties of the soil are the most important among the components that influence the soil's ability to give nutrients to plants and microorganisms. The chemical reactions that take place in the soil have an impact on the processes that lead to the soil development and the build-up of soil fertility. Microbial biomass, the living component of soil organic matter is thought to be the most labile C pool in soils and a sensitive indicator of changes in soil processes with links to soil nutrient and energy dynamics including mediating the transfer of soil organic carbon fractions (Haynes, 2008; Post and Kwon, 2000; Saha and Mandal, 2009; Weil and Magdoff, 2004). Assessment of soil-test properties from time to time has also been emphasized for evaluating the chemical aspects of soil quality (Arshad and Coen 1992; Karlen *et al.*, 1992).

2.2.1 Physical indicators

Gilley and Doran (1997) conducted a study on tillage effects on soil erosion potential and soil quality of a former conservation reserve program site and found that the NM (Nine months after tillage) treatment had the lowest dry bulk density of any of the experimental treatments at the 0-7.6 cm depth and the highest dry bulk density of any of the experimental treatments at the 0-30.5 cm depth. Undisturbed systems had a larger percentage of very fine silt and clay (34%) than four days following tillage and nine months following tillage which were 29 and 24 per cent, respectively. They also reported that cultivation practices redistribute clay content.

While studying the soil nutrient status of small holder farms in Malawi, Snapp (1998) showed that the soils were loamy sand in texture. The sand content in the Center and Northern regions was found to be 76.00 per cent and average sand content in the Southern region was slightly lower *i.e.,* 72.00 per cent.

Sharma *et al*. (2002) assessed the soil fertility ratings in Fatehpur block of Kangra district of Himachal Pradesh and found that the soils of majority of panchayats (68.1%) had moderately fine texture while 23.4 and 8.5 per cent of panchayats comprised of coarse and moderately coarse textured soils, respectively and soil textural classes varied from sand to silty clay loam.

According to Sharma and Kumar (2003), the bulk density of crop lands in the upper Maul khad catchment in wet temperate zone of Himachal Pradesh ranged from 1.55 to 1.72 Mg m^{-3}, while tea garden soils ranged from 1.35 to 1.40 Mg m^{-3}.

In a small watershed of middle hill region of Nepal, Regmi and Zoebisch (2004) assessed the soil fertility status of *Bari* (upland) and *Khet* (irrigated lowland) and reported that the bulk density of *Khet* land was generally higher than *Bari* land and the respective values were 1.36 and 1.28 Mg m^{-3}.

Kumar and Verma (2005) observed that the bulk density increased with depth with values ranging from 0.99 to 1.62 Mg m^{-3} in rice growing soils of Himachal Pradesh's Palam valley and that the texture of these soils were sandy loam and silty clay loam.

In the soils of the Sivagiri watershed in the Chittoor district of Andhra Pradesh, Thangasamy *et al.* (2005) reported low bulk density values of surface soils which might be attributed due to high organic matter content. They further observed that different pedon's water holding capacity varied between 13.05 to 58.99 per cent.

A study was conducted by Rao *et al.* (2006) to determine the available major nutrients in dominant soils of rainfed crop production systems of India and showed that in rainfed rice based production system, all the three profiles at Faizabad, Phulbani and Ranchi had mean clay content above 30.00 per cent and under pearl millet and maize production systems, profile mean clay content was above 30.00 per cent except in the soils at Hisar, S.K.Nagar, Arjia, Hoshiarpur and Rakh Dhiansar.

According to Mahajan *et al.* (2007) the value of bulk density increased with depth in almost all of the profiles which was evident due to the decreasing trend of organic carbon and particle density. Bulk density had higher value in vegetable growing soils than in paddy and maize growing soils.

According to Rao *et al.* (2008), the bulk density ranged from 1.45 to 1.66 Mg m^{-3} in soils of various physiographic units. The water holding capacity of various pedon's ranged from 19.96 to 47.81 per cent in the plains, 30.02 to 44.64 per cent in the uplands and 32.46 to 36.03 per cent on the hill slope.

Physical, chemical and biological parameters of soil quality in four land use systems of submontane tract of Punjab (Kandi region) were studied by Dhaliwal *et al.* (2009). They observed that soils in cultivated and forest land use systems possessed higher water holding capacity (56.4% and 57.4%), porosity (58% and 62%) than other land use systems. Bulk density was significantly less (1.57Mg m^{-3} and 1.53 Mg m^{-3}) in cultivated and forest land use systems compared to in pasture and undisturbed land use systems (1.59 Mg $m^{-3}$and 1.58 Mg m^{-3}).

According to Shekhar (2009), bulk density values in forest, grassland and cultivated regions were found between 1.14 to 1.31, 1.19 to 1.26 and 1.31 to 1.34 Mg m^{-3}, respectively in surface soils, whereas in subsurface soils it ranged from 1.31 to 1.48, 1.35 to 1.48 and 1.46 to 1.52 Mg m^{-3}, respectively. Surface soils in forest, grassland and cultivated regions had mean bulk density values of 1.2, 1.2 and 1.3 Mg m^{-3}, respectively, whereas subsurface soils had mean bulk density values of 1.4, 1.4 and 1.5 Mg m^{-3}, respectively.

Gupta *et al.* (2010) reported that in soils of barren, cultivated/unmanaged, cultivated/well managed and forest lands, water holding capacity ranged from 21.9 to 32.2, 30.5 to 40.5, 35.4 to 47.5 and 35.3 to 47.3 per cent, respectively. The average contents of clay, silt, fine sand and coarse sand (%) in soils of barren land profiles was 9.2, 20.1, 54.7 and 15.2, respectively and 14.0, 22.4, 47.8 and 15.5, respectively, in those of cultivated unmanaged lands. The per cent of clay, silt, fine sand and coarse sand in cultivated well-managed lands were 18.3, 23.7, 49.1 and 8.4, respectively, while in forest lands they were 21.2, 25.7, 43.3 and 9.4, respectively. Soils from barren areas had the highest bulk density (1.47 to 1.60 Mg m^{-3}) followed by those from cultivated unmanaged lands (1.46 to 1.58 Mg m^{-3}), cultivated well-managed lands (1.34 to 1.54 Mg m^{-3}) and forest lands (1.32 to 1.52 Mg m^{-3}).

In Himachal Pradesh's dry temperate zone, Sharma and Kanwar (2010) reported that silt and clay concentration ranged from 13.2 to 28.0 per cent and 4.0 to 23.2 per cent, with average values of 19.8 and 13.9 per cent, respectively.

Kumar and Babel (2011) assessed available micronutrient status and their relationship with soil properties of Jhunjhunu tehsil, district Jhunjhunu, Rajasthan and observed that the sand, silt and clay content of the soil ranged from 76.70 to 90.40, 1.30 to 7.50 and 5.20 to 12.90 per cent, respectively and categorized these soils as sandy, loamy sand and sandy loam.

Kyandiah (2012) observed that porosity varied between 33.82-38.60 per cent under different land use systems in the Shivalik mid hill zone of Himachal Pradesh.

Chander *et al.* (2014) conducted a study on vegetable growing soils of Himachal Pradesh's mid hills sub humid and high hills wet-temperate zones. They concluded that the soils of mid hills sub humid and high hills wet temperate zones were sandy loam to clay loam in texture with sand, silt and clay contents ranging from 22.4 to 78.8, 12.3 to 46.5, 8.9 to 38.6 per cent and 12.1 to 77, 10.7 to 41.6, 10-34.8 per cent, respectively.

Kalu *et al.* (2015) found that the texture of the soil common to all the land use types was sandy loam. Bulk density was found to be highest in pastures followed by agriculture soils and then forest soils. Soil moisture was found to be significantly different in the pasture and protected forest. The pasture consisted of the lowest soil moisture content due to the evaporation of soil water.

Ramana *et al.* (2015) in their study on available macronutrient status and their relationship with soil physico-chemical properties of Sri Ganganagar District of Rajasthan, India reported that the bulk density and particle density ranged from 1.03 to 1.74 and 1.67 to 2.63 Mg m^{-3} with a mean value of 1.30 and 2.25 Mg m^{-3}, respectively. The average water retention capacity of soil was 41.69 per cent with a range of 22.10 to 83.15 per cent. Low water holding capacity relative to other soils could be related to a lack of organic matter and clay.

While assessing soil fertility and mapping of spatial variability at Amareganda-Abajarso sub-watershed, North-Eastern Ethiopia, Abate *et al.* (2016) observed that the soil bulk density varied from 1.15 to 1.38 g cm^{-3}. The mean values of sand and clay fractions ranged from 67.33 to 43.4 and 40.93 to 12.67 per cent, respectively.

Chandel *et al.* (2017) assessed soil health under protected cultivation of vegetable crops in North West Himalayas and found that bulk density was lower in the polyhouse condition (1.18 Mg m^{-3}) than in the open condition (1.25 Mg m^{-3}). When compared to open conditions (42.20 %), polyhouse conditions showed higher porosity per cent (45.86%).

Biswas *et al.* (2017) investigated the impact of intensive cultivation on soil health under polyhouses located in Bilaspur, Solan and Sirmaur districts of Himachal Pradesh and found that the bulk density ranged from 1.09 to 1.13 Mg m^{-3} and particle density varied between 2.25 to 2.31 Mg m^{-3}, whereas the porosity ranged from 49.47 to 51.09 per cent.

Khadka *et al.* (2017) evaluated the soil fertility of regional agriculture research station, Tarahara, Nepal and found that the sand, silt and clay content were 30.32±1, 48.92±0.89 and 20.76±0.92 per cent, respectively and were categorized as loam, clay loam, sandy loam, silt loam and silty clay loam in texture.

Soil quality assessment through minimum data set under different land uses of submontane Punjab was done by Chandel *et al.* (2018) in which they found that the bulk density under the bare land use was maximum (1.34 Mg m^{-3}) followed by horticulture (1.30 Mg m^{-3}), grasses (1.29 Mg m^{-3}), forest (1.28 Mg m^{-3}) and least under cultivated (1.27 Mg m^{-3}). The maximum water holding capacity was observed in the forest land use (39.7%), which was significantly at par with the horticulture (38.7%) followed by grasses (36.9%) and cultivated land use (34.0%). Bare land use (27.6%) was found to be having least water holding capacity.

Kumar and Paliyal (2018) while determining physical and chemical properties of soils under mid hill humid conditions of North West Himalayas observed that soils were deep, well drained, silty loam to silty clay loam with dark brown to brownish yellow in colour. Regardless of soil depth, silty loam was the predominate texture of the soils. All sites had a higher proportion of coarse sand. Surface soil bulk density in vegetable growing regions, rice growing areas and maize producing areas ranged from 1.07 to 1.30, 1.09 to 1.32 and 1.09 to 1.29 Mg m^{-3}, respectively. It ranged from 1.0 to 1.28, 1.07 to 1.29 and 1.1 to 1.34 Mg m^{-3} in the subsurface layers, respectively.

Magare *et al.* (2019) analyzed the physico-chemical characteristics and status of available micro and secondary nutrients in soils of agro-ecological-sub-region 6.2 c (K4Dd4) Latur district of Maharashtra and reported that Nilanga tehsil of Latur district showed greater content of clay hence came under clay type textural class.

While studying the soil physico-chemical properties under some dominating vegetations of coastal Odisha, Mohaptra *et al.* (2020) indicated that soils under *Acacia nilotica* possessed highest bulk density (1.42 g cm^{-3}) whereas, *Mallotus philippensis* had lowest (1.27g cm^{-3}).

In Orlu, Imo state, South Eastern Nigeria, fertility status of soils under selected land use types were studied by Nkwopara *et al.* (2021) and they found that the bulk density was highest under oil palm (1.43 g cm^{-3}) and lowest under cassava (1.10 g cm^{-3}). The bulk density and porosity of the soils under plantain, oil palm and cassava varied from 1.03 to 1.52 g cm^{-3} and 40.60 to 59.80 per cent, respectively.

2.2.2 Chemical indicators

In vegetable growing pocket of cold desert area of Himachal Pradesh, Parmar *et al.* (1999) reported that the average organic carbon content in Spiti soils was low (0.56 to 0.78 %), whereas it was high (1.14 to 2.01 %) in Kinnaur soils. They also found that the amount of available Cu in soil varied from 0.09 to 0.70 mg kg^{-1} in Spiti soils and 0.11 to 0.92 mg kg^{-1} in Kinnaur soils. They further reported that high hills zone soils were deficient in DTPA-extractable Fe, Mn and Zn by 38 to 42, 22 to 34 and 42 to 65 per cent, respectively.

Mahajan (2001) found that the soils of Mandi district of Himachal Pradesh were medium in available N (384 to 492 kg ha^{-1}), P (17 to 22 kg ha^{-1}) and K (231 to 235 kg ha^{-1}) and high in exchangeable Ca (4.0 to 5.1 c mol (p+) kg^{-1}), Mg (1.7 to 2.4 c mol (p+) kg^{-1}), DTPA extractable Fe (91 to 129 ppm) and Mn (1.7 to 2.8 ppm).

According to Sharma *et al.* (2002), available N and P were low to high, available K was low to medium, exchangeable Ca and Mg was sufficient and available micronutrient cations were deficient to sufficient in Fatehpur block of Himachal Pradesh.

Kumar and Verma (2005) examined the fertility status of rice-growing soils in Himachal Pradesh's palam valley and revealed that the soils were low to medium in available N and P,but high in available K.

Status of macro and micronutrients in some soils of Tonk district of Rajasthan was studied by Meena *et al.* (2006) and they observed that the soil pH ranged from 7.10 to 8.60 with an average value of 7.80.

Mahajan *et al.* (2007) examined morphological, physical and chemical properties of soils in North West Himalayas and found that the soils were slightly acidic to neutral in reaction had medium to high levels of organic carbon, high levels of exchangeable bases (Ca^{2+} and Mg^{2+}) and moderate levels of available N, P and K. They also reported that these soils had high levels of DTPA-extractable Fe, Zn, Cu and Mn.

Mondol *et al.* (2007) found that the soils in the Chattha area of Jammu were low in available N, P and K but high in exchangeable Ca, Mg and S as well as micronutrient cations. In comparison to non-agricultural lands, agricultural lands have better soil fertility.

Singh (2008) revealed that the soils of seven states *viz.,* Madhya Pradesh, Punjab, Haryana, Bihar, Maharashtra, Tamil Nadu and Uttar Pradesh were deficient in available Cu, Mn, Zn and Fe to the extent of 3.6, 10.5, 35.0 and 18.6 per cent, respectively. In Himachal Pradesh, available Mn, Zn and Cu were deficient in 5.0, 42.0 and 27.0 per cent of soil samples, respectively.

While observing physical, chemical and biological parameters of soil quality in four land use systems of submontane tract of Punjab (Kandi region) Dhaliwal *et al.* (2009) found significantly higher levels of available and total zinc (1.26 mg kg^{-1} and 105.3 mg Kg^{-1}, respectively), copper (0.79 mg kg^{-1} and 29.77 mg kg^{-1}, respectively), iron (11.0 mg kg^{-1} and 3.6 mg kg^{-1}, respectively) and manganese (13.28 mg kg^{-1} and 835 mg kg^{-1}, respectively) in Ludhiana soils as compared to in forest land use system in Kandi area. Available nitrogen (264 kg ha^{-1}), total nitrogen (0.20%) and available potassium (384 kg ha^{-1}) were higher in forest land use system whereas, available (18.4 g ha^{-1}) and total phosphorus (96.7 kg ha^{-1}) were significantly higher in cultivated land use system as compared to pasture and undisturbed land use systems.

Devi and Kumar (2009) reported that the surface soil Cation exchange capacity levels ranged from 16.6 to 38.1 c mol (p^+) kg^{-1}. The cation exchange capacity of pea-growing soils in Himachal Pradesh's dry temperate zone ranged from 3.5 to 62.0 c mol (p+) kg^{-1} with an average value of 18.4 c mol (p^+) kg^{-1}, whereas organic carbon content ranged from 0.42 to 4.08 per cent and pH ranged from 6.2 to 10.3.

Pathak (2010) studied the trend of fertility status of Indian soils and based on the soil test values of N, P and K, soil samples were classified into three categories *i.e.,* low, medium and high, and nutrient index was calculated for soils of different states. Nitrogen fertility increased in many states, such as West Bengal, Gujarat and Tamil Nadu, but it decreased in Orissa and Kerala. The nitrogen fertility status in the remaining states stayed nearly constant from 1967 to1997. In Assam, Karnataka and Kerala, an increasing trend in soil P status was noticed. It stayed unmodified in the remaining states. Potassium fertility either stayed constant or decreased.

The fertility status of agricultural lands in Manipur was assessed by Sahoo *et al.* (2010) who categorised the soils as medium to high in available N (503 to 1078 kg ha^{-1}), low in available P (0.4 to 3 kg ha^{-1}) and low to high in available K (79 to 441 kg ha^{-1}). Iron, manganese, zinc and copper levels were sufficient ranging from 57.5 to 244.5, 36.0 to 85.5, 0.58 to 1.52 and 0.74 to 3.06 ppm, respectively.

Sharma and Kanwar (2010) reported that in Himachal Pradesh's dry temperate zone, the pH of soils ranged from 6.2 to 10.3 with a mean value of 7.6. Considering the organic carbon content of 0.5 per cent as low, 0.5-1.0 per cent as medium and >1.0 per cent as high, respectively, 2.0, 16.0 and 82.0 per cent of the soil samples had low, medium and high organic carbon content, respectively. When less than 0.2 mg kg^{-1} DTPA Cu was used as a critical limit, only 8.6 per cent of soil samples in dry temperate zone pea growing areas were found to be deficient in DTPA Cu.

Behera *et al.* (2011) analysed the total and extractable Zn levels in acidic Indian soils. The findings revealed that total and extractable Zn concentrations varied greatly among acid soils, as the amount of Zn extracted by different extractants. The contribution of soil organic carbon (OC) content towards total and extractable Zn was greater as compared to soil pH.

Kumar and Babel (2011) assessed the available micronutrient status and their relationship with soil properties and found that the analysed samples were low in organic carbon and CEC and ranged from 0.06 to 0.43 per cent and 2.40 to 10.40 c mol (p^+) kg^{-1}, respectively. The pH (8.10 to 9.20) and EC (0.20 to 2.14 dS m^{-1}) values indicated that soils were found to be moderately alkaline and non-saline in nature. Ninety per cent of analysed samples were found to be deficient in Fe and seventy per cent deficient in Zn and their values ranged between 1.22 to 5.87 and 0.12 to 1.30 mg kg^{-1}, respectively. Whereas, the remaining micronutrients (Cu, Mn and B) were observed to be sufficient and they ranged between 0.17 to 3.32, 2.03 to 5.67 and 0.37 to 1.51 mg kg^{-1}, respectively.

While characterizing the soils of lower Himalayas of Himachal Pradesh, India, Sharma and Dogra (2011) observed that the pH in Hamirpur district ranged between 7.0 to 7.8 and between 7.8 to 8.3 in Bilaspur district. In Hamirpur district, potassium was found to be in the range of 44.0 to 918.0 kg ha^{-1} whereas in Bilaspur district it ranged between 67.0 to

918.0 kg ha^{-1}. Zinc, Cu, Fe, Mn ranged between 0.6 to 2.33, 0.3 to 1.2, 4.2 to 7.1 and 0.4 to 0.85 ppm, respectively in Hamirpur district and in Bilaspur district Zn, Cu, Fe, Mn ranged between 0.6 to 1.3, 0.4 to 1, 4 to 8 and 1.8 to 23 ppm, respectively.

Soil fertility status of Sangamner area, Ahmednagar district, Maharashtra, India was evaluated by Deshmukh (2012) and observed that the pH ranged from 8.0 to 9.7 reflecting alkaline nature of soils. Organic carbon ranged between 0.165 to 1.575 per cent in the soils. Twenty nine and forty eight per cent of soils showed low and medium status of organic carbon respectively. Contents of potassium were found to be high while the contents of available nitrogen and phosphorus were low in the soils. Available boron ranged between 0.02 to 14.42 ppm and found to be higher in salt affected soils.

Sharma and Kanwar (2012) assessed the macronutrients availability in pea growing soils of dry temperate zone of Himachal Pradesh and observed that the soils were neutral to alkaline in reaction having pH in range of 6.2 to 10.3. The available N, P and K content of soils ranged from 94.0 to 517.0, 2.0 to 89.0 and 120.0 to 1497.0 kg ha^{-1} with an average value of 273.0, 25.0 and 504.0 kg ha^{-1}, respectively. The nitrogen deficiency was observed highest in the soils of Gondhla valley (73%) followed by Kinnaur (48 %), Spiti (46 %), Pattan valley (43 %) and Udaipur valley (28 %). In terms of phosphorus, 37 per cent of the soil samples had high available phosphorus and 12 per cent had low available phosphorous. Phosphorus deficiency was highest in Gondhla valley (33%) followed by Spiti (26%), Kinnaur (8%) and Udaipur (4%). Approximately 83 per cent of the soil samples were observed to be high in available potassium.

In a watershed of Semi-Arid Tropics in Southern India, Prabhavathi *et al.* (2013) assessed soil fertility status for sustainable crop production and revealed that nutrient index of organic carbon (g kg^{-1}), available N (kg ha^{-1}) and zinc (mg kg^{-1}) were very low and nutrient index was medium for available phosphorous and potassium in the watershed. The extent of deficiency of organic carbon, nitrogen and zinc was 63, 86 and 58 per cent, respectively.

Behera and Shukla (2014) assessed the total and extractable Mn and Fe contents of cultivated acidic soils in India including the Rajpora series in Himachal Pradesh. They reported that manganese deficiencies were found in 7.0 to 23.0 per cent of total soil samples based on the DTPA-extractable contents. In the Rajpora series of Himachal Pradesh, DTPA extractable Mn and Fe ranged from 0.30 to 69.7 and 29.5-326.0 mg kg^{-1} soil, respectively. Total Mn and Fe, on the other hand, were found in the range of 96.3 to 632.0 and 17400 to 49857 mg kg^{-1}, respectively. In acid soils, total and DTPA-extractable Mn and Fe levels were influenced more by soil organic carbon (SOC) than by soil pH.

Chander *et al.* (2014) in their study on vegetable growing soils of Himachal Pradesh's mid hills sub-humid and high hills wet-temperate zones observed that the soils were medium in available N, low to medium in available P and medium to high in available K. In sub-humid zone, the DTPA-extractable micronutrients ranged from 0.64 to 11.0 mg kg^{-1} for Zn, 0.14 to 2.80 mg kg^{-1} for Cu, 10.6 to 70.8 mg kg^{-1} for Fe and 2.1 to 34.9 mg kg^{-1} for Mn, while in wet-temperate zone these were between the range of 0.44 to 2.06 mg kg^{-1} for Zn, 0.02 to 3.60 mg kg^{-1} for Cu, 22.8 to 96.6 mg kg^{-1} for Fe and 2.5 to 40.0 mg kg^{-1} for Mn.

Ravikumar (2014) studied spatial distribution of macronutrients in soils of Markandeya river basin, Belgaum, Karnataka, India and reported that all of the soil samples had low available nitrogen concentration (29.1 to 189.5 kg ha^{-1}), fifty per cent of the samples had low to medium available phosphorous (0.96 to 15.1 $kgha^{-1}$) and ninety per cent of the samples had adequate available potassium (313.3 to 1500.8 $Kgha^{-1}$). For calcium the values varied from 14.2 to 57.0 meq 100 g^{-1} and magnesium the concentrations varied from 3.81 to 26.05 meq 100 g^{-1}.

While assessing the soil quality for different land use in the Panchase area of Western Nepal, Kalu *et al.* (2015) observed that the organic carbon content of soil was significantly higher in forest soils and pasture followed by agriculture land. Total nitrogen content of the forest soils was found to be significantly higher than that of pasture and agricultural land and available phosphorus was found to be significantly higher in the agriculture land followed by community forest, pasture and protected forest.

Kavitha and Sujatha (2015) found that the nitrogen content of the soils of the various agro ecosystems varied between 0.003 to 0.63 per cent and the phosphorous levels of the soils of various agro ecosystems varied between 0.1 to 847.7 ppm. Content of potassium in the soils of various agro ecosystems varied from 1.0 to 2914 kg ha^{-1}. The content of calcium and magnesium in the soils of various agro ecosystems varied from 20.6 to 351.05 ppm and 3.0 to 524.0 ppm, respectively and sulphur content in the soils of various agro ecosystems varied from 0.03 to 575.0 ppm.

Ramana *et al.* (2015) studied the available macronutrient status and their relationship with soil physico-chemical properties of Sri Ganganagar District of Rajasthan, India and reported that the pH of the soils tested ranged from 7.1 to 8.8, with an average of 7.84 and electrical conductivity ranged from 0.10 to 1.40 dS m^{-1} with an average value of 0.49 dS m^{-1}. These soils available nitrogen content ranged from 100.35 to 326.14 kg ha^{-1} with a mean value of 202.79 kg ha^{-1}. The amount of available phosphorus in these soils ranged from 0.15 to 32 kg ha^{-1}, with a mean of 25.59 kg ha^{-1}. The available potassium in these soils ranged from 290 to 482 kg ha^{-1}, with a mean of 367.57 kg ha^{-1}. These soils had an exchangeable calcium content ranging from 0.4-10.2 c mol (p^{+}) kg^{-1}, with an average of 5.9 c mol (p^{+}) kg^{-1}. Further, data showed that the exchangeable Mg^{2+} content in soils ranged between 0.5 to 8.6 c mol (p^{+}) kg^{-1} with a mean value of 4.11 cmol (p^{+}) kg^{-1}.

Abate *et al.* (2016) observed that the organic matter content of soils ranged from 1.33 to 3.70 per cent. The total N content ranged from 0.09 to 0.30 per cent. The available P content ranged from 9.31 to 19.53 mg kg^{-1} soil and the exchangeable K content ranged from 97.48 to 357.70 mg kg^{-1}. The highest [46.6 c mol (p^{+}) kg^{-1}] and lowest [33.47 c mol (p^{+}) kg^{-1}] values of CEC were recorded in LUs 8 and 5, respectively. Exchangeable Ca and Mg ranged from 9.25 to 23.35 and 2.76 to 8.50 c mol (p^{+}) kg^{-1}, respectively. The EDTA extractable Fe, Mn, Cu and Zn ranged from 56.03 to 96.19, 65.30 to 226.48, 1.84 to 6.19 and 1.12 to 4.34 mg kg^{-1}, respectively.

Khadka *et al.* (2016) assessed the soil fertility status of agriculture research station, Belachapi, Dhanusha, Nepal and observed that the pH of the soil was acidic (5.61). The status of available sulphur (0.73 ppm) was very low, whereas the status of organic matter (1.34 per cent), available boron (0.56 ppm), zinc (0.54 ppm) and copper (0.30 ppm) were also poor. Extractable potassium (95.52 ppm) and calcium (1264.8 ppm) were moderate in status. In addition, status of available phosphorus (33.25 ppm), magnesium (223.20 ppm) and manganese (20.50 ppm) was high. Furthermore, available iron (55.80 ppm) status was very high.

Soil fertility status of mid Himalayan region of Himachal Pradesh was assessed by Annepu *et al.* (2017) and they found that the pH of soil ranged from 6.59 to 7.81 with mean pH of 7.36. Electrical conductivity of soil ranged between 0.049 to 0.793 dS m^{-1} with a mean value of 0.426 dS m^{-1}. The available N content in soils varied from 201.21 to 603.37 kg ha^{-1} with an average value of 312.91 kg ha^{-1}. They further found that the available P content of mid Himalayan soils varied from 7 to 45 kg ha^{-1} with a mean value of 21.41 kg ha^{-1} and available K in the soils of the study area ranged from 70.56 to 448 kg ha^{-1} with an average value of 193.83 kg ha^{-1}.

Amara *et al.* (2017) evaluated the fertility status of soils using nutrient index approach and reported that the soil pH in the five villages ranged from acidic to alkaline. The mean value of EC was 0.1 dS m^{-1} with a range varying from 0.0 to 0.27 dS m^{-1}. Exchangeable Ca and Mg contents ranged from low to high as the content of calcium in the soils varied from 3.2 to 33.6 meq 100 g^{-1}, while the magnesium content varied from 1.9 to 23.2 meq 100 g^{-1}.

Micronutrient availability was found to be highly variable, zinc levels were low to medium, iron levels were low, manganese and copper levels were low to high.

Basavaraja *et al.* (2017) conducted a study in the Hassan district of Karnataka to assess the nutritional status and their findings revealed that around eighty six per cent of soil samples had medium available nitrogen (315.90 kg ha^{-1}) and fifty five per cent had high available phosphorus (>22.50 kg ha^{-1}). The amount of available potassium in different taluka's surface soils ranged from 50 to 984 kg ha^{-1}. The available sulphur level in soil ranged from 0.24 to 90.81 mg kg^{-1} with 75 per cent of soil samples being sulphur deficient due to crop sulphur removal.

Biswas *et al.* (2017) assessed the soil health under protected cultivation by soil quality indexing and variability analysis in three districts of Himachal Pradesh and observed that the soil reaction was neutral (7.08 to 7.34) and EC values were in safe limits (<0.8 dS m^{-1}). The percent of organic carbon ranged from 1.76 to 2.00 per cent. N, P and K availability ranged from 246.1 to 264.8, 49.5 to 61.9 and 587.1 to 682.5 kg ha^{-1}, respectively. The exchangeable Ca and Mg levels in the soils were found to be adequate and the sulphur concentration was moderate. Under both polyhouse and open conditions, the availability of Zn, Fe, Cu and Mn was medium to high.

Under protected cultivation of vegetable crops in North West Himalayas, Chandel *et al.* (2017) assessed the soil health and found that organic carbon in the soil ranged from 1.37 to 1.76 per cent. Available nitrogen was found to be high in polyhouse conditions with a mean value of 320.81 kg ha^{-1} than in open condition having mean 287.64 kg ha^{-1}. The exchangeable calcium and magnesium was found more under polyhouse condition than open conditions. In comparison to open conditions (2.31 mg kg^{-1}), polyhouses soil had a higher zinc concentration.

Singh *et al.* (2017) studied the soil fertility status of Majhwa block of Mirzapur district of Eastern UP, India and found that the available N, P, K and S content in surface (0-20 cm) soils was higher than in subsurface soils (20-40 cm). Surface soils (0-20 cm) had 306.0, 18.4, 229.0 and 9.8 kg ha^{-1} accessible N, P, K and S, respectively, whereas subsurface soil (20-40 cm) had 241.0, 20.4, 189.0 and 8.57 kg ha^{-1} available N, P, K and S, respectively. In both the surface and subsurface soils, the mean DTPA extractable Fe, Cu, Mn, Zn and hot water soluble B content followed a similar pattern of distribution. In top soils, the maximum concentrations of Fe, Cu, Mn, Zn and B were 15.2, 6.2, 3.11, 2.63 and 1.47 mg kg^{-1}, respectively. In surface soils (0-20 cm), the mean values of water soluble cations Ca, Mg, Na and K were 19.3, 9.59, 9.07 and 11.7 meq L^{-1}, respectively.

Chandel *et al.* (2018) assessed soil quality through minimum data set under different land uses of submontane Punjab and recorded that the pH under most of the land uses was moderately alkaline to alkaline in nature varying from 7.9 to 8.2. Electrical conductivity was found to be significantly higher (0.26 dS m^{-1}) under cultivated land use followed by grasses (0.19 dS m^{-1}), horticulture (0.18 dS m^{-1}) and least (0.16 dS m^{-1}) under forest (0.16 dS m^{-1}) and bare land use (0.16 dS m^{-1}). The soil organic carbon content was found to be significantly higher under land use forest (8.4 g kg^{-1}). Available N was highest under the land use forest (151.8 kg ha^{-1}) and least in bare land use (100.8 kg ha^{-1}). The available P was reported medium (12.2 to 24.2 kg ha^{-1}) to high (>24.2 kg ha^{-1}) and available K was low (<133 kg ha^{-1}) under all the land uses.

The available nitrogen, phosphorus, potassium and sulphur content in soils of Gujarat's Ghandhi nagar district ranged from 78.6 to 376.3, 18.61 to 69.57, 114.24 to 645.33 kg ha^{-1} and 6.74 to 30.06 mg kg^{-1}, respectively with mean value of 231.8, 41.06, 306 kg ha^{-1} and 18.97 mg kg^{-1}, respectively. Out of 160 soil samples analysed, 79.38 per cent had low available nitrogen, 71.88 per cent had medium available phosphorus, 50 per cent had high available potassium and 48.75 per cent had high available sulphur (Chavda *et al*., 2018).

Assessment of soil fertility under different land use systems in Dhading district of Nepal was done by Kharal *et al.* (2018) in which they found that the pH of the soil in the vegetable fields was neutral (6.61) but the rest of the land use systems had acidic soils. Forest soil organic matter (3.55 %) and nitrogen (0.18%) content were much greater, although highland and lowland farms had the lowest soil organic matter (1.26 %) and nitrogen (0.06 %) content, respectively. The vegetable farm had the most available phosphorous (41.07 mg kg^{-1}), whereas pasture land had the lowest (2.89 mg kg^{-1}). Phosphorous levels were substantially greater on the upland farm (39.89 mg kg^{-1}) than on the lowland farm (9.02 mg kg^{-1}). The vegetable farm had the most available potassium (130.2 mg kg^{-1}) as compared to pasture land (36.8 mg kg^{-1}).

Soil fertility status of some agricultural areas in El -Kharaga Oasis, New Valley, Egypt was checked by Gameh *et al.* (2018) and they found that thirty five per cent of the samples had low available nitrogen and sixty five per cent had medium nitrogen which was associated with low organic matter (100% of the samples had less than 1% OM). However, ninety one per cent of the samples have high available phosphorous (>15mg kg^{-1}), whereas five per cent and four per cent of the samples were categorized as low and medium in available phosphorous, respectively. They also observed that only two per cent of samples analysed were medium in available potassium and ninety eight per cent were high in available potassium and according to EC results, forty nine per cent of the samples had EC less than 4 dS m^{-1}.

Krishna *et al.* (2018) conducted research to assess the fertility condition of the Palari block in the Baloda bazar district of Chhattisgarh and found that the available nitrogen concentration ranged from 102 to 277 kg ha^{-1} with a mean value of 157 kg ha^{-1}. Available phosphorus ranged from 1.34 to 26.61 kg ha^{-1} with a mean value of 13.8 kg ha^{-1}, while available potassium content ranged from 113 to 567 kg ha^{-1} with an average value of 238 kg ha^{-1}.

Kumar *et al.* (2018) analysed the physical and chemical properties of soils under prevalent cropping systems in Kinnaur district of Himachal Pradesh and observed that soil pH at the surface in the cropping systems pea-fallow-wheat, maize-fallow-rajmash and maize-fallow-wheat ranged from 5.3 to 8.2, 5.9 to 7.2 and 5.6 to 6.8 respectively. In the subsurface soil, it ranged from 5.3 to 6.7, 5.7 to 7.0 and 5.6 to 6.6, respectively. Organic carbon content in surface soils under cropping system pea-fallow-wheat, maize-fallow-rajmash and maize- fallow-wheat systems ranged between 0.97 to 3.06, 1.3 to 3.06 and 1.30 to 2.91 per cent, respectively whereas, in the subsurface layers it varied from 0.90 to 2.90, 0.90 to 2.97 and 1.21to 2.88 per cent in respective system. Under different cropping systems, mean available nitrogen content (200.13 kg ha^{-1}) was found in the low group but phosphorous (75.1 kg ha^{-1}) and potassium (610.20 kg ha^{-1}) were found in the medium category.

Vista *et al.* (2019) assessed the soil fertility status of the vegetable super zone in Kaski Nepal and concluded that the total nitrogen content of the study area ranged from 0.08 to 0.53 per cent falling into the low to very high category and the mean nitrogen content was 0.24 per cent falling into the very high category. The soil available phosphorus ranged from 8 to 182 mg kg^{-1} in the very low to very high range with a mean phosphorus concentration in the middle range. The amount of available potassium varied between 0 to 1980 kg ha^{-1} falling into the very low to very high group with a mean value of 240 kg ha^{-1} which falls under medium category.

Magare *et al.* (2019) analyzed the physico-chemical characteristics and status of available micro and secondary nutrients in soils of agro-ecological-sub-region 6.2 c (K4Dd4) Latur district of Maharashtra and found that the organic carbon content in soils of the studied area ranged from 3.86 to 7.54 g kg^{-1} with a mean value of 5.46 g kg^{-1}. The available sulphur content varied from 10.18 to 14.58 with a mean of 12.43 mg kg^{-1} and was found to be medium in category. The exchangeable calcium ranged from 14.65 to 31.45 c mol (p+) kg^{-1}) and magnesium from 12.12 to 27.65 c mol (p+) kg^{-1} with means of 23.32 and 20.63 c mol (p+) kg^{-1}, respectively. They further reported that the DTPA extractable zinc, copper, iron, manganese and boron varied from 0.39 to 0.87, 3.61 to 10.08, 18.32 to 32.00, 30.62 to 65.94 and 0.28 to 0.55 mg kg^{-1} with mean of 0.56, 6.04, 28.69, 46.98 and 0.37 mg kg^{-1}, respectively.

Salve and Bhardwaj (2020) in their study on soil carbon stock and nutrient in different agroforestry systems at Kinnaur district, Himachal Pradesh found highest potassium content in agrisilviculture system (1.29 mg 100 g^{-1}) followed by agrihorticulture system (1.26 mg 100 g^{-1}) and agrihortisilviculture system (1.21 mg 100 g^{-1}). They also reported maximum exchangeable calcium content in agrihorticulture systems (5.52 mg 100 g$^{-1)}$ followed by agrisilviculture systems (5.21 mg 100 g^{-1}) and agrihortisilviculture systems (5.19 mg 100 g^{-1}) and maximum exchangeable magnesium content in agrisilviculture system (4.30 mg 100 g^{-1}) followed by agrisilvihorticulture system (4.06 mg 100 g^{-1}) and agrisilviculture system (4.00 mg 100 g^{-1}).

A study was conducted by Nkwopara *et al.* (2021) to evaluate the fertility status of soils under selected land use types in Orlu, Imo state, South Eastern Nigeria. They observed that under different land uses the mean available phosphorus and potassium content ranged from 1.10 to 11.50 mg kg^{-1} and 0.10 to 0.20 c mol kg^{-1}, respectively.

2.2.3 Biological indicators

Van Gestel *et al.* (1992) reported that the timing of soil sample has a big impact on the average microbial biomass carbon. The winter samples had the greatest average value (308 µg g^{-1} soil), although this value was not significantly different from that of the monsoon samples (305 µg g^{-1} soil). Summer samples had the lowest average value (253 µg g^{-1} soil) when salinity was at its peak and the weather was hot.

Karlen *et al.* (1994) studied the soil respiration under three tillage systems and found that the undisturbed system (352 mg C kg^{-1} soil) had higher soil respiration than the deep tillage system (139 mg C kg^{-1} soil) and the conventional cultivated system (74 mg C kg^{-1} soil). Karlen *et al.* (1997) found similar results in organically (manures and legumes as cover crops) and conventionally managed system.

According to Doran and Zeiss (2000), soil organisms are important indicators of soil quality and determinants of soil health. Land management strategies and climate have an impact on soil organisms. They are linked to a variety of important soil and ecological processes such as water storage, decomposition and nutrient cycling, toxicant detoxification and suppression of noxious and pathogenic organisms.

Marinari *et al.* (2006) assessed the effects of organic and conventional farming methods on soil quality indicators at the farm level using chemical and microbiological properties as soil quality indicators and measured them at soil depth intervals of 5-20 and 20-35 cm after seven years of organic certified and conventional management methods and they revealed that the organically managed field had much better soil nutritional and microbiological conditions with higher microbial biomass content and enzymatic activity (acid phosphatase, protease and dehydrogenase). They further found no consistent increase in total organic carbon and the findings of their study suggested that organic management methods have a strong impact on soil quality indicators over seven years period and that there are significant differences between the two soils in terms of microbiological properties, which are sensitive soil indicators of changes that occur under different farming systems.

Mandal *et al.* (2007) used a field experiment to study the effect of six long-term (34 years) fertiliser and farmyard manure (FYM) treatments (Control, N, NP, NPK, NPK + S and NPK + FYM) and three physiological stages of wheat growth on microbial biomass carbon (MBC), nitrogen (MBN), mineralizable N, dehydrogenase and phosphatase activities in soil. They observed that a balanced application of NPK + FYM produced the highest values for the tested parameters while delivering the lowest at the control. The tillering stage had the highest values followed by flowering and dough.

Tripathi *et al.* (2006) examined the state of microbial biomass carbon in the Bay of Bengal's Sunderbans coastal soil and observed that the average microbial biomass in the different study locations ranged from 125 - 446 µg g^{-1} and the values were greater in soils with higher organic carbon content.

Dhaliwal *et al.* (2009) found that levels of potentially mineralizable nitrogen (10.26µg g^{-1}), microbial biomass carbon (120.6 µg g^{-1}), microbial biomass nitrogen (39.7 µg g^{-1}) and soil respiration (3.77 µg g^{-1}) were significantly higher in Ludhiana district as compared to forest, cultivated, pasture or undisturbed land use systems in the Kandi area while observing physical, chemical and biological parameters of soil quality in four land use systems of submontane tract of Punjab (Kandi region).

According to Hao *et al.* (2009), soil microbial carbon (C) content was higher in intensive greenhouse tomato soils than in neighbouring open conditions. The soil microbial biomass C was significantly correlated with both soil total N and soil organic matter but there was no significant relationship between soil microbial biomass N, soil total N and organic-matter content.

In the pre-monsoon season, Khajuria (2010) discovered that microbial biomass in Nalagarh, Baddi and Barotiwala area in the Solan district ranged from 35.78 to 89.87, 34.16 to 108.83 and 42.93 to 128.45 mg 100 g^{-1} soil, respectively. Similarly, Kaushal (2011) examined the state of microbial biomass in the Nauni area of Solan district and found that it ranged from 40 to 120 mg 100 g^{-1} of soil.

Aslam *et al.* (2015) examined the effect of three different land use systems on microbial biomass nitrogen levels in surface soil (0-10 cm). Undistributed systems had higher microbial biomass nitrogen levels (116 kg ha^{-1}) than pasture systems (113 kg ha^{-1}) and cultivated systems (80 kg ha^{-1}). They also examined the effect of season on microbial biomass nitrogen and observed that the fall season had a higher turnover rate than the summer season which was followed by the winter season under three land use system.

While assessing the soil health under protected cultivation by soil quality indexing and variability analysis in three districts of Himachal Pradesh, Biswas *et al.* (2017) observed that the microbial biomass ranged from 322.65-385.343 µg g^{-1} falling under medium range for categorizing soil health.

Chandel *et al.* (2017) assessed the soil health under protected cultivation of vegetable crops in North West Himalayas and reported that microbial biomass ranged from 377.13 - 459.57 µg g^{-1} under different conditions. The value of microbial biomass was found to be much higher in the polyhouse in comparison to the open situation.

Chandel *et al.* (2018) assessed soil quality through minimum data set under different land uses of submontane Punjab and they found that under different land uses, the soil microbial biomass followed the following pattern: Grasses (129.06 µg g^{-1}) > forest (92.24 µg g^{-1}) > horticulture (83.15 µg g^{-1}) > cultivated (82.03 µg g^{-1}) > bare (68.13 µg g^{-1}) whereas forest land use had the highest labile carbon content (0.73 mg g^{-1}) which was comparable to land use cultivated (0.68 mg g^{-1}), horticulture (0.62 mg g^{-1}), grasses (0.59 mg g^{-1}) and bare land use (0.42 mg g^{-1}).

2.3 Effect of vegetable cultivation on soil properties

Lin *et al*. (2004) reported that the microbial biomass carbon content decreased significantly in protected soils as compared to open field vegetable soils and due to continuous vegetable cultivation under the plastic greenhouse conditions; the bacterial population decreased dramatically, whereas the fungal and actinomycetes amount was considerably increased as compared to open conditions.

While exploring the changes of soil chemical properties under vegetable in greenhouse with respect to their adjacent open fields, Liu *et al.* (2005) observed that the contents of soil organic carbon and total nitrogen in greenhouse fields were significantly higher. Soil nitrate content in greenhouse fields was approximately 12.49 times as much as that in open fields. Also with the increasing age of greenhouse field, soil pH decreased, while soil soluble salts accumulated.

Lu *et al*. (2006) reported that continuous cucumber mono cropping under protected system contributed to the secondary soil salinization, imbalanced soil nutrient status, phosphorus in excessive amount and potassium content deficient in the soils.

Chen *et al*. (2007) reported accumulation of organic matter, nitrate, available phosphorus and potassium in the greenhouse soils. The cation exchange capacity (CEC) in the greenhouse soils was also higher than that in the open fields. On the contrary, the soil pH of the greenhouse declined. There was no significant difference in the content of exchangeable calcium between the open fields and greenhouse soil.

In North East China, Ju *et al*. (2007) observed that substantial mineral N and available P and K accumulated in the greenhouse soils. Soil pH under vegetables was significantly lower than in the wheat–maize fields, while the EC was significantly higher in the vegetable soils. They further reported that due to excessive fertilizer application in greenhouse vegetable production, excessive salt and nitrate concentrations might accumulate and soil quality might deteriorate faster than in conventional wheat–maize rotations.

Huang *et al.* (2009) found that to pursue higher yields excessive application of fertilizers in vegetable fields is being done. In some areas, the fertilization rates are several times of those needed by vegetables. Nitrogen and phosphorous are accumulated in the vegetable soils resulting in the poor quality of vegetables.

In the Northern China plain, Qiu and Ju (2010) reported that the rate of nitrogenous fertilizers and irrigation application in greenhouse vegetable systems is about three to five times more than the conventional vegetable systems. Over a decade of shifting from the conventional cultivation systems to greenhouse cultivation system, the capacity for nutrient cycling within those greenhouse systems had fallen with a dramatic decline in the content of inorganic carbon in the soil profile.

Sun *et al*. (2011) found that clay was lower in upper layer than in deeper layer, indicating their downward movement and this phenomenon was more obvious with increasing year of greenhouse vegetable cultivation. Within the first 5 years of solar greenhouse vegetable cultivation, field water capacity decreased significantly with a decrement of 13.8% but remained relatively stable after then.

While studying the effects of intensive fertilization on the yields of tomato and soil physical and chemical properties in newly-built greenhouse over a season of tomato crop, Gao *et al.* (2012) reported that the contents of organic matter, total nitrogen, available phosphorus and available potassium in soil increased after one growing season and significant increase was observed for organic matter and available phosphorus. The electrical conductivity in the 0-100 cm soil layer also increased to some degree.

The impact of intensive cultivation on soil health under polyhouses located in Bilaspur, Solan and Sirmaur districts of Himachal Pradesh was investigated by Biswas *et al*. (2017) and they revealed that under polyhouse conditions in various districts, bulk density ranged from 1.09 to 1.13 Mg m^{-3}. The soil reaction was neutral (7.08 to 7.34) and EC values were in safe limits (<0.8 dS m^{-1}). The organic carbon content varied from 1.76 to 2 percent. Available N, P and K were ranged from 246.1 to 264.8, 49.5 to 61.9 and 587.1 to 682.5 kg ha^{-1}, respectively.

In North West Himalayas, Mandi, Solan and Sirmour districts of Himachal Pradesh, Chandel *et al.* (2017) evaluated the soil health under protected and open cultivation of vegetable crops and indicated that the majority of the soils in polyhouse conditions were in high soil health condition accounting for 57% of the surveyed samples, followed by the very high (40%) and medium soil health (3%). Whereas, in case of open condition majority of the soils were at high health level (53%) followed by very high (27%) and medium soil health (20%). Soil health was found to be affected by the management practices adopted by the farmer and the extent of fertilizer use over a period of time.

2.4 Relationship among soil properties and crop productivity

2.4.1 Relationship among soil properties

In the soils of Himachal Pradesh, Tripathi and Singh (1992) found a highly positive significant (r= 0.68**) correlation between sulphate and organic carbon. The sulphate sulphur concentration decreases significantly as clay concentration rises (r= -0.44**), showing that clay fractions retain more of this form of sulphur in the soil. They also found a significant correlation between DTPA-Fe and organic carbon (r= 0.55**) indicating that the amount of accessible Fe in soils is largely determined by the amount of organic carbon present.

Garcia *et al.* (1994) reported that soil microbial population was less during periods when temperature and moisture conditions are low, while it peaked during rainy season when the litter decomposition rate is at its peak on the forest floor. Weak correlations were also obtained for the relationships between microbial C, N and P and soil physico-chemical properties in both gaps and under stories, microbial C, N and P showed strong positive correlations with soil moisture, soil temperature, air temperature, litter layer thickness and light intensity. Microbial nutrients were also influenced by soil parameters such as clay content, WHC, pH, SOC and available P.

In some soils of Nagaur district in semi arid region of Rajasthan, Sharma *et al.* (2003) studied the correlation on micronutrients with soil properties and reported that Zn, Cu, Fe and Mn was positively correlated with silt plus clay and organic carbon content and showed negative correlation with soil pH.

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

In comparison to other overburden sites, the microbial biomass C, N and P in forest soil was expectedly higher. Since soil microbial biomass is dependent on soil organic matter as a substrate, a drop in soil organic C will result in a reduction in soil microbial biomass (Chen *et al.*, 2005).

In some soils of Tonk district of Rajasthan, Meena *et al.* (2006) analyzed the status of macro and micronutrients and reported a significant positive correlation between organic carbon and available N (r = 0.639**), P (r = 0.797**) and K (r = 0.420**) content. Also, a significant negative correlation (r = -0.195*) was observed between soil pH and available Cu and significant positive correlation was also observed between Fe and Cu with clay content (r = 0.180* for Fe and r = 0.196* for Cu).

Rao *et al.* (2006) determined the available major nutrients in dominant soils of rainfed crop production systems of India and showed that correlation coefficients varied from significantly negative to positive. Also, organic carbon showed significantly positive correlation with available N, P and K in most of the profiles and with S in many profiles.

According to Amacher *et al.* (2007) more heavily weathered soils tend to have lower organic carbon and nutrient contents as well as lower pH levels and higher acidity than soils in less intensively weathered regions of the country. Soil organic matter levels influenced soil bulk density because higher amounts of lighter weight soil organic carbon resulted in lower bulk densities.

Sharma *et al.* (2008) analysed the soils of Punjab's Amritsar district and found that available nitrogen was positively and significantly correlated with organic carbon. Organic carbon and clay content were found to have a significant positive relationship with available potassium.

While evaluating the fertility status in arecanut garden soils of Karnataka, Shetty *et al.* (2008) reported significant positive correlation between available nitrogen and organic carbon. Furthermore, a significantly negative relation between available phosphorus and pH was also noted while that with organic carbon was positive. Potassium had negative significant correlation with EC and clay complex. Organic carbon and pH had significant positive relation with exchangeable calcium and magnesium.

Yadav and Meena (2009) concluded that the soil pH was negatively and significantly correlated with Fe and Cu.

Kumar *et al.* (2009) also revealed a positive correlation between available N and organic carbon content (r= 0.838**) in Lachimpur series of Santhal Paraganas region of Jharkhand.

In the soils of Madhya Pradesh, Trivedi *et al.* (2010) reported a negative and highly significant relationship of EC with available P. A negative and non-significant correlation between available micronutrients and EC in soils of Rajasthan was observed by Bhanwaria *et al.* (2011).

According to Sharma and Kanwar (2012), DTPA-Mn is negatively correlated with soil pH but has a significantly positive relationship with organic carbon.

Khokhar *et al.* (2012) revealed that the sand and silt was significantly and positively correlated with soil pH (r = 0.776**) and (r = 0.412*) but was significantly and negatively related with available nitrogen. Available N showed a significant but negative relationship with soil pH (r = -0.469*). Furthermore, a highly significant and negative correlation was observed between soil N and EC (r = 0.522**). Available Mn showed non-significant but negative relationship with pH, but significant and negative relationship with EC. Also, available Cu, Fe and Zn showed non-significant and negative relationship with pH and EC. It was also reported that the available N improves the availability of P (r = 0.533**), K (r = 0.622**) and Cu (r = 0.437*).

Chaudhari *et al.* (2013) examined the relationships between soil physical and chemical properties like $CaCO_3$, organic matter content, total macro and micro nutrient content and bulk density and they reported that soil bulk density had negative relationship with all soil properties ($CaCO_3$, organic matter content, total macro and total micro nutrient content).

Chander *et al.* (2014) in their study on vegetable growing soils in Himachal Pradesh's mid hills sub humid and high hills found that organic carbon has a positive correlation with all of the DTPA micronutrients and the soil pH was negatively correlated with DTPA-Fe and Mn.

The fertility status of alluvial, medium black soils and ravenous land of Chambal region of Madhya Pradesh was studied by Singh *et al.* (2014) and they found that the available N, P, K, S, Fe, Cu, Zn and Mn were negatively and significantly correlated with soil pH and available N and P but positively correlated with K and S. They further reported that available N, P, K, S, Fe, Cu, Zn and Mn were significantly and positively correlated with organic carbon and silt plus clay content in soil.

Ramana *et al.* (2015) reported that particle density and water holding capacity had negative correlation with nitrogen. Electrical conductivity of soil (r= -0.098) and bulk density (r= -0.140) has negative non-significant correlation with phosphorus. Available phosphorus had significant negative correlation with organic carbon content (r = -0.219*) and water holding capacity (r = -0.282**). Available sulphur in these soil had significant relationship with pH (r= 0.341*) and non-significant correlation with organic carbon (r=0.099), bulk density (r= 0.140), water holding capacity (r= 0.070) and negatively non-significant relationship with electrical conductivity (r= -0.10) and particle density (r= -0.046).

Singh *et al.* (2016) conducted a study to assess the soil fertility status of Tedia village in the Varanasi district of Uttar Pradesh and they came to the conclusion that available nitrogen, phosphorus and potassium were positively correlated with pH and organic carbon and negatively correlated with EC.

Annepu *et al.* (2017) studied the soil fertility status of mid Himalayan region of Himachal Pradesh and found a strong and positive correlation between available nitrogen (r= 0.351**) and organic carbon. Available nitrogen had a significant positive correlation with available phosphorous (r= 0.263**). The available Zn in the soil has significant negative relationship with pH (r = -0.484**).

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

According to Kashiwar *et al.* (2018) soil pH was positively correlated with EC, OC, N, P, K, S and Zn. Soil EC was found to have a positive relationship with OC, N, P, K, S, Zn Fe and Cu. Organic carbon was observed to have a positive relationship with available N, P, K, S, Zn, Cu and Mn. Phosphorous, K, S, Zn, Cu and Mn all had a significant and positive relationship with available nitrogen. The available phosphorus was found to be significantly correlated to K, S, Cu, Mn, Fe and Zn. Positively significant correlations were found between exchangeable potassium and S, Zn, Cu and Mn. The available sulphur in the soil exhibited a positive and significant relationship with Zn, Fe and Cu but a negative and non-significant relationship with Mn.

Kingsley *et al.* (2019) showed that Fe gave a significant correlation with Zn, Mn, S, pH and organic carbon at the Ekpri Ibami hillslope. Copper had a positive correlation with Zn, Mn and S, but a negative but statistically significant correlation with clay. Zinc correlated positively and significantly with Mn, sand and clay, but significantly negative with organic carbon.

While studying the fractionation of sulphur with different physico-chemical properties of cultivated soils from North Western Himalayas, Sharma and Sankhyan (2020) observed that sulphur availability was significantly and positively affected by organic matter and finer soil particles.

In Orlu, Imo state, South Eastern Nigeria, Nkwopara *et al.* (2021) studied the fertility status of soils under selected land use types, they concluded that the available phosphorus had a significant negative correlation with K: Mg ratio. Also, exchangeable Ca and Mg had a significant negative correlation with K: Mg ratio.

2.4.2 Relationship between soil properties and crop productivity

A study was conducted by Gbadegesin (1986) on the method for identifying soil properties influencing maize crop yield in the Savanna belt of South Western Nigeria and found a high negative correlation between sand content and all the maize parameters, high positive correlations between the silt and clay contents of the topsoil and the maize parameters were also observed. Water holding capacity showed a strong and positive correlation with all the maize parameters. Soil porosity was found to have a strong influence on the growth and yield of maize as evidenced by the high positive correlations between the two. The soil chemical properties were also observed to have a strong influence on growth and yield of maize in the study area.

Effect of soil and topographic properties on crop yield in a North Central corn–soybean cropping system was studied by Jiang and Thelen (2004) and they found that the soil pH and Mg concentration showed a significant correlation with the corn and soybean yield.

Papiernik *et al.* (2005) evaluated the variation in soil properties and crop yield across an eroded prairie landscape and reported that the wheat yield was positively correlated with soil organic carbon content and inversely correlated with the soil pH.

In sandy soils of Xuzhou (China), Jiang *et al.* (2006) worked out the relationship between soil health parameters and productivity of wheat and maize and found that there was a positive correlation between soil organic matter and wheat (r = 0.630) and maize yield (r = 0.658).

Marathe and Bharambe (2007) studied the correlation of integrated nutrient management induced changes in soil properties with yield and quality of sweet orange (*Citrus sinensis*) on udic haplustert and reported that the changes in available nutrients in the soil were positively correlated in regulating the fruit yield.

A study was conducted by Jagadamma *et al.* (2008) on nitrogen fertilization and cropping system impacts on soil properties and their relationship to crop yield in the Central Corn Belt, USA and revealed that the corn grain yield was positively correlated to organic carbon and total nitrogen content and negatively correlated to soil pH, Mg^{2+} and K^{+}.

Prabhavathi *et al.* (2010) studied the influence of sources and levels of potassium on quality attributes and nutrient composition of red chillies and revealed that the highest correlation coefficients (0.855** and 0.909**) were observed in case of colour value and per cent oleoresin, respectively with K concentration of whole red chilli fruit.

A study on comparing farmers perception of soil fertility change with soil properties and crop performance in Beseku, Ethiopia was carried out by Karltun *et al.* (2013) and they showed that the decline in maize biomass was strongly correlated (r = 0.95) with the total N content of the soils and the soil with the highest production of biomass had a significantly higher available P content.

While studying the effect of forty-one years of fertilizer and FYM application on crop yield and soil quality under rice-wheat sequence in a silty clay loam soil of Pantnagar

(Uttarakhand), Ram *et al.* (2016) reported that soil organic carbon and grain yield of rice (r = 0.625) and wheat (r = 6.40) crops were positively correlated. Similar observations have been reported by Meena and Sharma (2016) while investigating the long-term effect of fertilizers and amendments under maize-wheat cropping system in an acid *Alfisol* at Palampur (Himachal Pradesh). They documented that there was a positive correlation between maize and wheat grain yield with soil organic carbon, soil microbial biomass carbon and soil microbial biomass nitrogen.

From the study carried out by Singh *et al.* (2017) in *Typic Hapludalf* soils of Palampur (Himachal Pradesh) under maize-wheat cropping sequence, it was concluded that yield of maize and wheat was significantly and positively correlated with soil pH, cation exchange capacity, available N, P and K. They further reported that yield was negatively correlated with bulk density of soil.

Choudhary *et al.* (2018) carried out a field study in a silty clay loam soils of Almora (Uttarakhand) to determine the impact of twenty-one years of continuous application of inorganic fertilizers and organic manure on yield and soil health in soybean-wheat cropping system. The results indicated that yield of soybean was significantly and positively correlated with available N, P, Fe, Mn, Zn and Cu.

In a similar study, a significant positive correlation was found between soil nutrients, straw and grain yield in rice by Gosal *et al.* (2018) while studying the effect of long-term integrated use of organic and inorganic fertilizers at Ludhiana (Punjab) on soil nutrient status and yield of rice suggesting that nutrient level in soil has significant effect on crop yield.

Whetton *et al.* (2021) evaluated the the influence of soil properties on crop yields using a non-linear finite impulse response model and laboratory data and they concluded that the highest correlation of (0.239) was calculated between OC and the crop yield.

Chapter-3

MATERIALS AND METHODS

The chapter entitled “material and methods” has been presented under the following heads:

3.1 General description of the study area

3.2 Selection of soil sampling sites

3.3 Collection and preparation of soil samples

3.4 Field studies, collection and preparation of leaf samples

3.5 Laboratory studies

3.6 Soil quality assessment

3.7 Statistical analysis

3.1 General description of the study area

3.1.1 Location and extent

Himachal Pradesh is predominantly a mountainous state located in North-West India. It lies between 30° 22' to 33° 12' N latitude and 75° 45' to 79° 04' E longitude within altitude of 350 to 6975 m above mean sea level. Physiographically, the state is divided in to four agroclimatic zones viz. (i) Sub tropical sub montane and low hills (Zone I), (ii) Sub humid mid hills (Zone II), (iii) Wet temperate high hills (Zone III), and (iv) Dry temperate high hills (Zone IV). Sub tropical sub montane and low hills (Zone I) consist of district Bilaspur, Hamirpur, Una and parts of Sirmour, Kangra, Solan and Chamba. It occupies about 35% of the geographical area and about 40% of the cultivated area of the state.

3.1.3 Climate

Sub tropical sub montane and low hills zone is generally characterized by the subtropical climate. Mean annual temperature lies between 15 to 23°C. The average annual rainfall is about 1100 mm.

3.1.4 Soils

The soils of the sub tropical sub montane and low hills zone are generally shallow to deep in depth, coarse textured, non calcareous to calcareous and low in fertility status (Gupta and Chera, 1996). These are neutral in reaction with pH varying from 6.5 to 7.5. *Entisols* are predominant in hill tops and side-slopes, while *Inceptisols* occur mainly on fluvial valleys and alluvial plains. The soil of this zone is mixed in clay mineralogy (Sidhu *et al*., 1997).

3.2 Selection of soil sampling sites

A survey was carried out in cauliflower growing areas in Hamirpur, Una and Bilaspur districts for assortment of necessary information about cultivation practices and cropping patterns. Three farmers in each block who were growing vegetables in more than 800 m^2 area and have completed three to five years of vegetable cultivation were selected randomly. Location of the selected sites has been described in table 3.1.

Table 3.1 List of sampling sites of vegetable growing areas in Hamirpur, Una and Bilaspur districts of Himachal Pradesh

Sr. No.	Name of the Farmer	Site (village)	Location		Elevation (m)
			Latitude	Longitude	
District- Hamirpur					
Block- Bamson					
1.	Surjeet Kumar	Gulela	31°39′09″N	76°33′30″E	723M
2.	Parveen Kumar	Kangroo	31°40′18″N	76°33′18″E	740M
3.	Ashok Kumar	Halana	31°38′33″N	76°32′54″E	690M
Block- Bhoranj					
4.	Kuldeep Singh	Jhandwin Changria	31°37′44″N	76°40′14″E	892M
5.	Virender Sharma	Ghamarwin	31°39′40″N	76°40′01″E	810M
6.	Shalig Ram	Bagwar	31°38′22″N	76°40′38″E	813M
Block- Bhijari					
7.	Ramesh Chand	Bilkar Kahan	31°36′29″N	76°33′15″E	753M
8.	Dilbag Singh	Patera	31°37′13″N	76°33′26″E	720M
9.	Hem Singh	Salan	31°35′42″N	76°32′12″E	827M
Block- Hamirpur					
10.	Naresh Kumar	Kakru	31°42′12″N	76°30′48″E	810M
11.	Vivek Kumar	Karahlar	31°43′47″N	76°30′15″E	730M
12.	Shiv Kumar	Khagal	31°41′04″N	76°28′05″E	640M
Block- Nadaun					
13.	Ashutosh	Bharmoti	31°45′32″N	76°20′52″E	432M
14.	Sharvan	Mewli	31°45′53″N	76°19′47″E	440M
15.	Veeru	Kohla	31°46′10″N	76°19′31″E	409M
Block- Sujanpur					
16.	Amar Singh	Bhalana	31°45′40″N	76°30′14″E	729M
17.	Sunny Kumar	Tikkar	31°45′23″N	76°23′57″E	758M
18.	Kishorilal	Chaunki	31°47′04″N	76°29′23″E	742M

			District- Una		
			Block- Amb		
19.	Prempal	Amb	31°40′14″N	76°06′44″E	410M
20.	Pramod Kumar	Pramb	31°40′58″N	76°07′25″E	404M
21.	Gurnam Singh	Heera Nagar	31°42′00″N	76°06′17″E	450M
			Block- Bhangana		
22.	Kailash	Malangar	31°35′18″N	76°22′58″E	480M
23.	Rajinder Kumar	Amrera	31°34′53″N	76°23′09″E	490M
24.	Des Raj	Surda	31°36′32″N	76°21′47″E	503M
			Block- Gagret		
25.	Tarsem Singh	Dolatpur	31°46′31″N	76°00′01″E	495M
26.	Mahesh Kumar	Ghanari	31°46′37″N	76°01′01″E	450M
27.	Gurpreet Singh	Deoli	31°44′39″N	76°02′78″E	440M
			Block- Haroli		
28.	Tirhat Ram	Shatarpur	31°22′18″N	76°19′58″E	301M
29.	Pyara Lal	Ghaluwal	31°29′09″N	76°12′12″E	370M
30.	Sanjay Saini	Bhadsali	31°31′14″N	76°12′40″E	390M
			Block- Una		
31.	Ramesh Rana	Fatehpur	31°23′26″N	76°18′07″E	330M
32.	Ashwany Kumar	Sasan	31°24′28″N	76°18′11″E	313M
33.	Dipty Kumar	Lal Singhi	31°28′40″N	76°14′55″E	405M
			District- Bilaspur		
			Block- Bilaspur Sadar		
34.	Nanak Ram	Manman	31°18′18″N	76°45′35″E	540M
35.	Manohar Lal	Panjel Khurd	31°16′29″N	76°51′52″E	763M
36.	Raj Kumar	Samari	31°21′42″N	76°48′29″E	650M
			Block- Ghumarvin		
37.	Yashvant Singh	Bhadrog	31°27′50″N	76°41′19″E	672M
38.	Kartar Singh	Jahri	31°28′24″N	76°40′46″E	710M
39.	Rajat Thakur	Loharwin	31°27′01″N	76°43′32″E	650M
			Block- Jhanduta		
40.	Dharam Singh	Galian	31°22′46″N	76°39′27″E	630M
41.	Satish Kumar	Behran	31°21′50″N	76°39′19″E	608M
42.	Satpal Singh	Amroha	31°23′10″N	76°38′11″E	529M
			Block- Shri Naina Devi Ji		
43.	Asha Ram	Dabheta	31°13′43″N	76°42′53″E	1014M
44.	Mangal Singh	Kutahla	31°15′23″N	76°43′44″E	980M
45.	Ram Murti	Kulah	31°14′28″N	76°43′51″E	995M

3.3 Collection and preparation of soil samples

Soil samples at a depth of 0-15 cm were collected from forty-five locations in fifteen blocks of Hamirpur, Una and Bilaspur district during the months of September. The soil samples from uncultivated area within the selected field under study (termed as buffer) were also collected to fulfill the objectives of the present investigation. Ninety representative soil samples collected from the sites of selected farmer fields under vegetable cultivation along with buffer plots after the harvesting of previous crop were air dried and ground in wooden pestle and mortar to break clods and then subsequently passed through a 2 mm sieve and stored in cloth bags for soil analysis. For the biological studies, the soil samples were used immediately after collection (fresh samples) for analysis.

3.4 Field studies, collection and preparation of leaf samples

Cauliflower yield during selected duration (October 2020 to February 2021) was recorded for different pickings and summed up after completion of the harvesting at the selected locations.

Cauliflower leaf samples were also collected from the vegetable growing fields from where the soil samples were collected during December-January, 2021. Most recent, fully matured leaf at heading stage were collected as per the recommendations of Kensworthy (1964), Reuter and Robinson (1986) and processed for analysis as per the methodology suggested by Chapman (1964).

The cauliflower leaf samples were washed with tap water and then with 0.1 N HCl and further with double distilled water. After this, leaf samples were air dried and then oven dried at 60 to 65˚C for 72 hours. The leaf samples were ground with the help of stainless steel grinder for proper mixing of plant materials and stored in butter paper bags for further analysis.

3.5 Laboratory studies

3.5.1 Soil analysis

Soil samples collected from the selected sites were analyzed for various physical, chemical and biological properties. The physical variables included texture, water holding capacity and bulk density. Whereas, chemical variables determined during the present study were pH, electrical conductivity (EC), organic carbon (OC), soil available N, P, K, S,

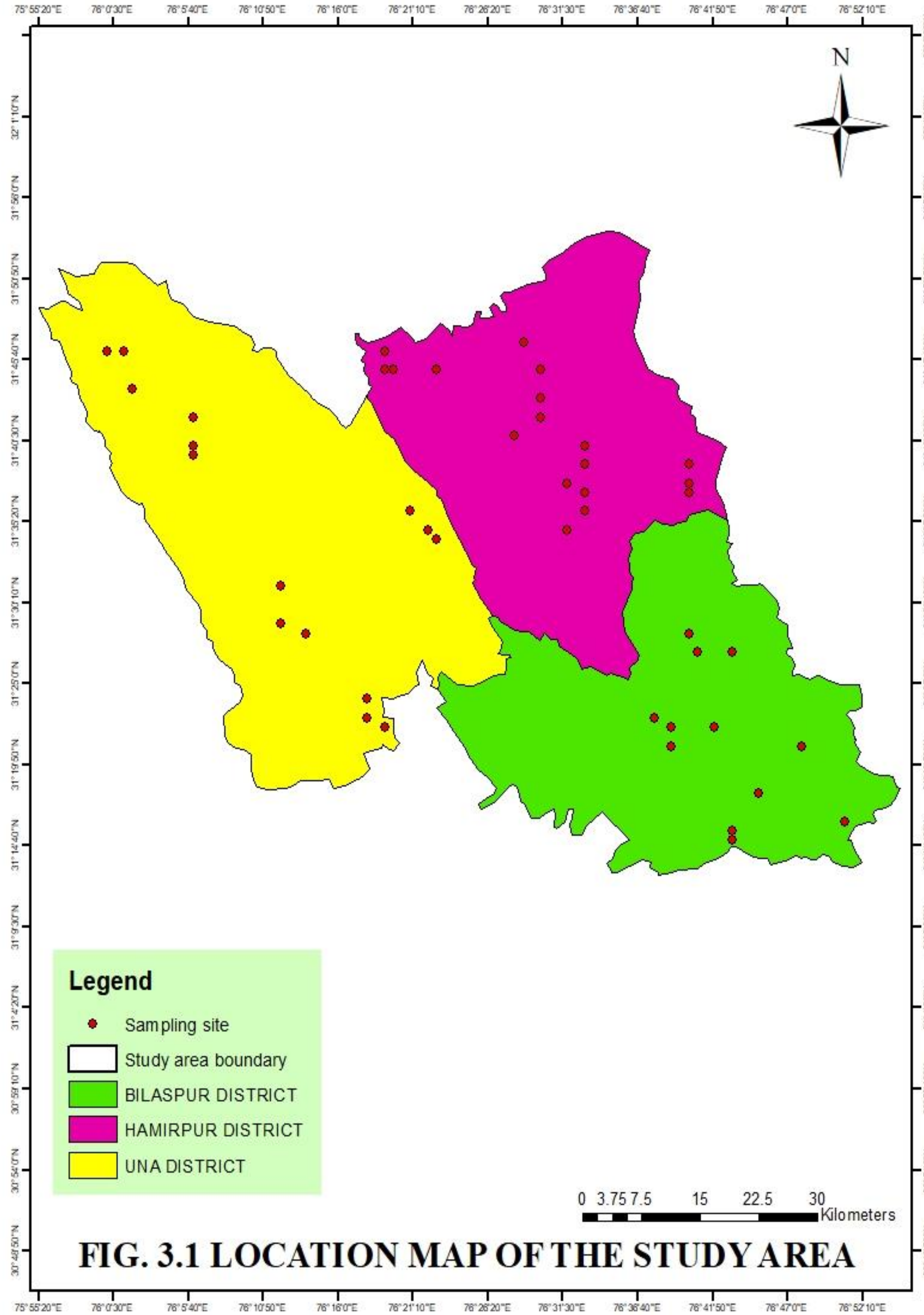


FIG. 3.1 LOCATION MAP OF THE STUDY AREA

exchangeable calcium (Ca) and magnesium (Mg) and DTPA-extractable micronutrient (Fe, Zn, Cu and Mn). Microbiological properties included microbial biomass carbon and nitrogen (MBC and MBN) and soil respiration.

Table 3.2 Analytical methods used for soil analysis

Sr. No.	Soil Property	Method Followed	Reference
1	Bulk density	Pycnometer method	Blake and Hartge (1986)
2	Soil texture	Hydrometer method	Bouyoucos (1927)
3	Maximum water holding capacity	Keen's method	Piper (1950)
4	Soil pH	Potentiometric method	Jackson (1973)
5	Electrical conductivity	Conductimetric method	Jackson (1973)
6	Organic carbon	Rapid titration method	Walkley and Black (1934)
7	Available nitrogen	Alkaline potassium permanganate method	Subbiah and Asija (1956)
8	Available phosphorus	Olsen′s method	Olsen *et al*. (1954)
9	Available potassium	Neutral 1N ammonium acetate method	Merwin and Peach (1951)
10	Exchangeable calcium	Flame photometric method	Sarma *et al*. (1987)
11	Exchangeable magnesium	Atomic absorption spectrophotometric method	Sarma *et al*. (1987)
12	Available sulphur	Turbiditeric method	Chesnin and Yien (1950)
13	DTPA-extractable micronutrients	DTPA-$CaCl_2$-TEA Exctraction method	Lindsay and Norvell (1978)
14	Soil Respiration	Carbon dioxide evolution method	Stotzky (1965)
15	Microbial Biomass Carbon (MBC)	Fumigation-extraction method	Vance *et al.* (1987)
16	Microbial Biomass Nitrogen (MBN)	Chloroform fumigation method	Jenkinson and Ladd (1981)

3.5.2 Leaf analysis

Leaf sample were analyzed for total N, P, K, S, Ca, Mg, Fe, Zn, Cu and Mn by using standard methods given in table 3.3.

Table 3.3 Analytical methods used for leaf analysis

Sr. No.	Nutrient	Method Followed	Reference
1	Nitrogen	Micro-kjeldhal′s methods	A.O.A.C. (1970)
2	Phosphorus	Diacid mixture digestion, vando-molybdate yellow color method	Jackson (1973)
3	Potassium and Calcium	Diacid mixture digestion, Flame photometric method	Jackson (1973)
4	Sulphur	Diacid mixture digestion, Turbiditeric method	Chesnin and Yien (1950)
5	Mg, Fe, Zn, Cu and Mn	Diacid mixture digestion, Atomic absorption spectrophotometric method	Jackson (1973)

3.6 Soil quality assessment

Soil performs many functions simultaneously however, for relating indicator properties to specific functions, the process is quite difficult. Over the last few years, researchers and farmers alike have tried to establish physical, chemical and biological indicators that can be used in soil quality assessment. Quality indicators so determined are required to be reduced to minimum dataset (MDS), following various successive steps of data analysis. For this principal component analysis (PCA) (Doran and Parkin, 1994; Andrews *et al.*, 2002) was used as a data reduction technique in the present study.

Principal components (PC) for a dataset are defined as linear combinations of variables that account for maximum variance within the set by describing vectors of close fit to the ′n′ observation in p-dimensional space. Principle component analysis (PCA) is a mathematical procedure that transforms several (possibly) correlated variables into a (smaller) number of uncorrelated variables (PC). The objective of PCA is to reduce the dimensionality of the parameter dataset and to identify new meaningful underlying variables, knowing that the PC’s are dependent on the units used to measure the original variables as well as on the range of values they assume. The first PC accounts for as much of the variability in the data as possible and each succeeding component accounts for as much of the remaining variability as possible.

The various successive steps of analysis followed to identify key indicators and to compute SQI included the following:

(i) fixing or defining the goals

(ii) Principal component analysis to select representative minimum data set (MDS)

(iii) correlation analysis among soil variables to reduce spurious grouping among highly weighted variables within each PC,

(iv) scoring of the MDS indicators based on their performance of soil function and computation of SQI. After determining the minimum data set (MDS) indicators using data reduction technique (PCA), each of the MDS variables was scored using linear scoring method on the basis of the performance of soil function, considering soil type and variation of values within soil. Each variable was transformed or standardized to a value between 0 (least favorable soil function) and 1 (most favorable soil function) through indicator transformation (Liebig *et al.,* 2001). For weight, variation percentage in particular PC was divided by the cumulative percentage of variation in all PCs. The final formula for computing SQI was as follows:

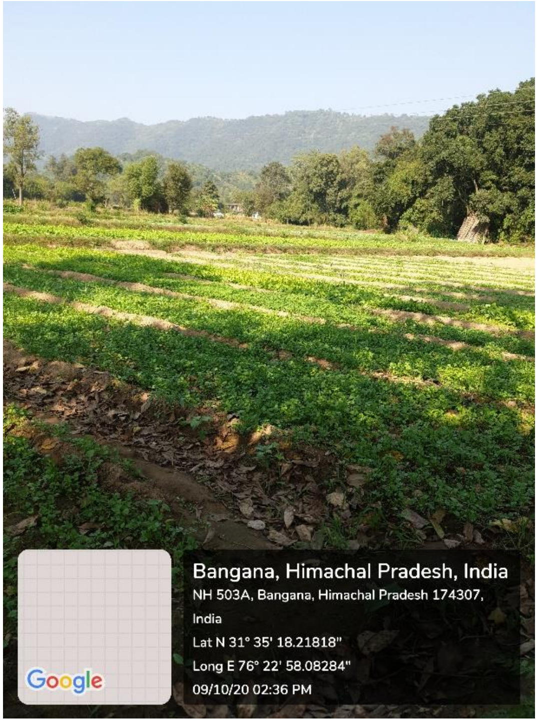
$$SQI = \sum_{i=1}^{n} WiXSi$$

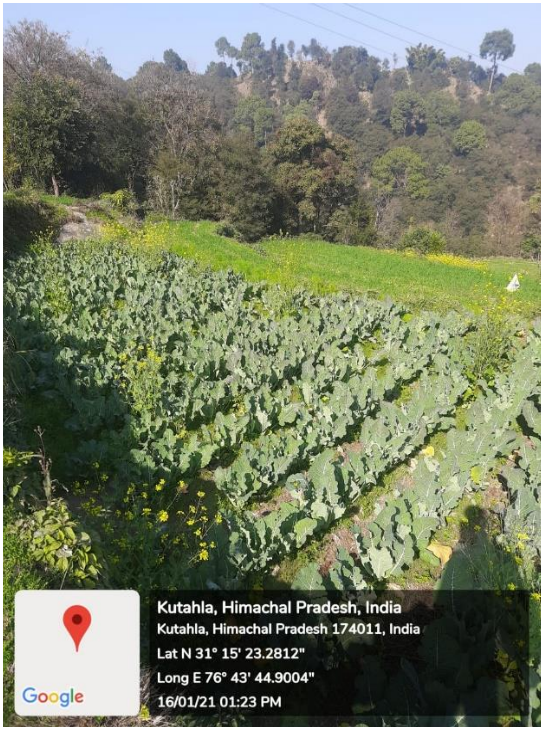
where, Wi is the PC weighting factor and Si is the indicator score. Here, the notion is that a higher index score meant better soil quality or greater performance of soil functions.

(v) Soil quality index was classified according to the criteria given by (Li *et al.*, 2018)

3.7 Statistical analysis

Descriptive statistic was performed to compare different sites. Correlation study was conducted among different parameters of soil and crop yield to compare their relativeness. PCA study was conducted for data reduction using XLSTAT, 2017 window version among various parameters to determine the effect of vegetable cultivation on soil quality indicators.





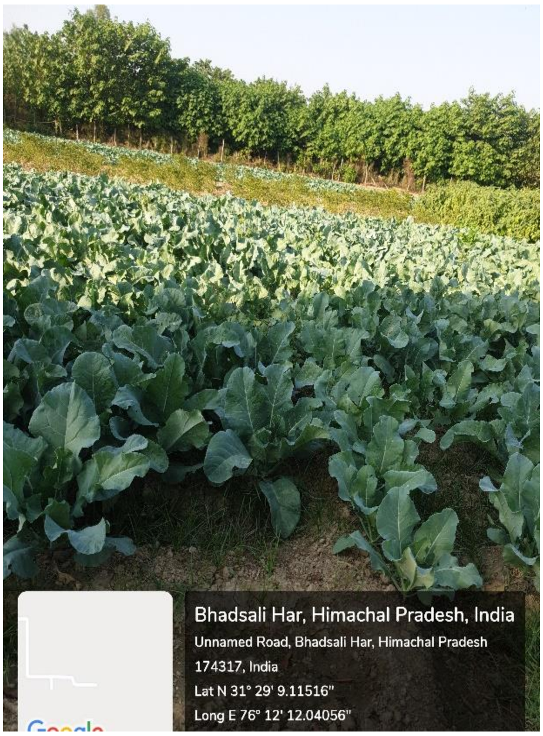


Plate 1 Collection of soil and leaf samples

Chapter-4

RESULTS AND DISCUSSION

The results emanating from the present investigation entitled "Assessment of soil health under vegetable cultivation of sub-montane and subtropical zone of Himachal Pradesh" have been presented and discussed in this chapter under the following heads:

4.1 Status of physico-chemical and microbiological properties of soils

4.1.1 Physical properties

4.1.2 Chemical properties

4.1.3 Microbiological properties

4.2 Assessment of soil health

4.3 Yield

4.4 Nutrient concentration in cauliflower leaves

4.5 Relationship among soil properties and crop productivity

4.5.1 Relationship among soil characteristics

4.5.2 Relationship of soil properties with yield and nutrient content of leaves

4.1 Status of physico-chemical and microbiological properties of soils

4.1.1 Physical properties

The soil physical environment serves as the key to modifications of chemical and biological functions of soils. Data pertaining to the status of various physical properties of soil are presented in table 4.1 and 4.2.

i. Soil Texture

A scrutiny of data presented in table 4.1 revealed that the soils of the studied area varied in texture. The sand, silt and clay contents in the cultivated conditions of district Hamirpur varied from 47.20 to 82.40, 14.00 to 44.00 and 3.60 to 8.80 per cent with the mean values of 69.46, 24.28 and 6.26 per cent, respectively. Whereas under buffer conditions sand, silt and clay varied from 51.00 to 82.80, 12.00 to 43.00 and 2.64 to 9.65 per cent with mean values of 69.65, 24.00 and 6.35 per cent, respectively. In the district, 66.67 per cent of the soil samples were found to have sandy loam texture, 27.77 per cent were loamy sand and

Table 4.1 Status of the texture of soils under cultivated and buffer conditions

Block	Sites	Cultivated				Buffer			
		Sand (%)	Silt (%)	Clay (%)	Textural class	Sand (%)	Silt (%)	Clay (%)	Textural class
District- Hamirpur									
Bamson	Gulela	72.20	22.00	5.80	*sl*	73.20	20.00	6.80	*sl*
	Kangroo	73.30	21.00	5.70	*sl*	70.34	24.00	5.66	*sl*
	Halana	67.36	24.00	8.64	*sl*	63.35	27.00	9.65	*sl*
	Mean	70.95	22.33	6.72		68.96	23.67	7.37	
Bhoranj	Jhandwin Changria	67.20	24.00	8.80	*sl*	70.10	21.00	8.90	*sl*
	Ghamarwin	64.20	30.00	5.80	*sl*	66.30	27.00	6.70	*sl*
	Bagwar	49.36	44.00	6.64	*sl*	51.36	43.00	5.64	*sl*
	Mean	60.25	32.67	7.08		62.59	30.33	7.08	
Bijhari	Bilkar Kahan	75.36	19.00	5.64	*ls*	76.36	18.00	5.64	*ls*
	Patera	67.40	26.00	6.60	*sl*	69.40	24.00	6.60	*sl*
	Salan	82.40	14.00	3.60	*ls*	81.36	16.00	2.64	*ls*
	Mean	75.05	19.67	5.28		75.71	19.33	4.96	
Hamirpur	Kakru	61.20	30.00	8.80	*sl*	57.20	34.00	8.80	*sl*
	Karahlar	76.40	20.00	3.60	*ls*	74.80	22.00	3.20	*ls*
	Khagal	81.20	14.00	4.80	*ls*	82.80	12.00	5.20	*ls*
	Mean	72.93	21.33	5.74		71.60	22.67	5.73	
Nadaun	Bharmoti	71.40	22.00	6.60	*sl*	73.60	19.00	7.40	*sl*
	Mewli	47.20	44.00	8.80	*l*	51.00	40.00	9.00	*l*
	Kohla	71.40	22.00	6.60	*sl*	68.40	26.00	5.60	*sl*
	Mean	63.33	29.33	7.33		64.33	28.33	7.33	
Sujanpur	Bhalana	81.36	15.00	3.64	*ls*	82.36	14.00	3.64	*ls*
	Tikkar	70.20	22.00	7.80	*sl*	71.90	20.00	8.10	*sl*
	Chaunki	71.20	24.00	4.80	*sl*	69.80	25.00	5.20	*sl*
	Mean	74.25	20.34	5.41		74.68	19.67	5.65	
District Mean		69.46	24.28	6.26		69.65	24.00	6.35	
District Range		47.20-82.40	14.00-44.00	3.60-8.80		51.00-82.80	12.00-43.00	2.64-9.65	
District- Una									
Amb	Amb	73.10	23.00	3.90	*sl*	73.40	22.00	4.60	*sl*
	Pramb	71.20	22.00	6.80	*sl*	68.40	25.00	6.60	*sl*
	Heera Nagar	76.20	18.00	5.80	*ls*	75.50	18.00	6.50	*sl*
	Mean	73.50	21.00	5.50		72.43	21.67	5.90	
Bangana	Malangar	72.20	19.00	8.80	*sl*	71.10	22.00	6.90	*sl*
	Amrera	75.20	18.00	6.80	*sl*	70.50	22.00	7.50	*sl*
	Surda	71.40	23.00	5.60	*sl*	69.70	24.00	6.30	*sl*
	Mean	72.93	20.00	7.07		70.43	22.67	6.90	
Gagret	Dolatpur	63.40	31.00	5.60	*sl*	65.70	28.00	6.30	*sl*
	Ghanari	70.80	20.00	9.20	*sl*	68.50	22.00	9.50	*sl*
	Deoli	74.20	20.00	5.80	*sl*	71.20	22.00	6.80	*sl*

	Mean	69.47	23.67	6.86		68.47	24.00	7.53	
Haroli	Shatarpur	52.40	39.00	8.60	*sl*	53.50	38.00	8.50	*sl*
	Ghaluwal	61.20	32.00	6.80	*sl*	57.20	34.00	8.80	*sl*
	Bhadsali	51.20	40.00	8.80	*l*	50.40	42.00	7.60	*l*
	Mean	54.93	37.00	8.07		53.70	38.00	8.30	
Una	Fatehpur	69.20	25.00	5.80	*sl*	66.80	27.00	6.20	*sl*
	Sasan	57.20	33.00	9.80	*sl*	60.30	29.00	10.70	*sl*
	Lal Singhi	57.30	33.00	9.70	*sl*	55.20	35.00	9.80	*sl*
	Mean	61.23	30.34	8.43		60.77	30.33	8.90	
District Mean		66.41	26.40	7.19		65.16	27.33	7.51	
District Range		51.20-76.20	18.00-40.00	3.90-9.80		50.40-75.50	18.00-42.00	4.60-10.70	
				District- Bilaspur					
Bilaspur Sadar	Manman	73.36	19.00	7.64	*sl*	77.80	14.30	7.90	*sl*
	Panjel Khurd	66.80	26.00	7.20	*sl*	68.50	24.00	7.50	*sl*
	Samari	73.60	17.00	9.40	*sl*	72.20	19.00	8.80	*sl*
	Mean	71.25	20.67	8.08		72.83	19.10	8.07	
Ghumarw-in	Bhadrog	73.20	20.00	6.80	*sl*	70.90	22.00	7.10	*sl*
	Jahri	73.20	22.00	4.80	*sl*	72.30	23.00	4.70	*sl*
	Loharwin	68.40	23.00	8.60	*sl*	65.36	25.00	9.64	*sl*
	Mean	71.60	21.67	6.73		69.52	23.33	7.15	
Jhanduta	Galian	69.20	20.00	10.80	*sl*	70.00	18.00	12.00	*sl*
	Behran	67.20	23.00	9.80	*sl*	65.60	24.00	10.40	*sl*
	Amroha	78.80	15.00	6.20	*ls*	79.20	13.00	7.80	*ls*
	Mean	71.74	19.33	8.93		71.60	18.33	10.07	
Shri Naina Devi Ji	Dabheta	70.36	23.00	6.64	*sl*	67.36	26.00	6.64	*sl*
	Kutahla	72.20	22.00	5.80	*sl*	68.40	27.00	4.60	*sl*
	Kulah	67.20	26.00	6.80	*sl*	70.20	22.00	7.80	*sl*
	Mean	69.92	23.67	6.41		68.65	25.00	6.35	
District Mean		71.13	21.33	7.54		70.65	21.44	7.91	
District Range		66.80-78.80	15.00-26.00	4.80-10.80		65.36-79.20	13.00-27.00	4.60-12.00	
Overall mean		68.90	24.21	6.89		68.48	24.26	7.26	
Overall Range		47.20-82.40	14.00-44.00	3.60-10.80		50.40-82.80	12.00-43.00	2.64-12.00	
Standard Error		0.98	1.47	0.71		0.96	1.46	0.75	
CV		11.80	29.90	27.40		11.60	30.10	28.20	
Standard Deviation		8.14	7.23	1.89		7.94	7.22	2.02	

Note: sl=sandy loam;
ls=loamy sand;
l=loam

remaining 5.56 per cent were loam in texture in both cultivated and buffer conditions as shown in the figure 4.1.

In district Una, sand, silt and clay contents varied from 51.20 to 76.20, 18.00 to 40.00 and 3.90 to 9.80 per cent with the mean values of 66.41, 26.40 and 7.19 per cent, respectively. Whereas, under buffer conditions sand, silt and clay contents varied from 50.40 to 75.50, 18.00 to 42.00 and 4.60 to 10.70 per cent with mean values of 65.16, 27.33 and 7.51 per cent, respectively. Under both cultivated and buffer conditions, 86.66 per cent of the soil samples were found to have sandy loam texture, 6.67 per cent were loamy sand and remaining 6.67 per cent were loam in texture as shown in figure 4.1.

In Bilaspur district, contents of sand, silt and clay ranged from 66.80 to 78.80, 15.00 to 26.00 and 4.80 to 10.80 per cent with mean values of 71.13, 21.33 and 7.54 per cent, respectively. Under buffer conditions sand, silt and clay content ranged from 65.36 to 79.20, 13.00 to 27.00 and 4.60 to 12.00 per cent with mean value of 70.65, 21.44 and 7.91, respectively. As illustrated in figure 4.1, 91.67 per cent of the soil samples were found to have sandy loam texture and remaining 8.33 per cent were loamy sand in texture under both cultivated and buffer conditions.

Sand, silt and clay contents under cultivated conditions in the overall studied area varied from 47.20 to 82.40, 14.00 to 44.00 and 3.60 to 10.80 per cent with mean values of 68.90, 24.21 and 6.89. Under buffer conditions sand, silt and clay content in the overall studied area ranged from 50.40 to 82.80, 12.00 to 43.00 and 2.64 to 12.00 per cent with mean value of 68.48, 24.26 and 7.26, respectively. The figure 4.1 shows that in overall under both conditions, 80.00 per cent of the soil samples were found to have sandy loam texture and 15.56 per cent were loamy sand in texture and remaining 4.44 per cent were loam in texture. Almost similar status of soil texture in vegetable growing soils of sub-humid and wet-temperate zones of Himachal Pradesh was also reported by Chander *et al.* (2014). The result are in trend line with the findings of Kumari *et al.* (2018), Suri (2018) and Arshad (2020) in different areas of Himachal Pradesh.

ii. Bulk density

The data presented in the table 4.2 revealed that in Hamirpur district the bulk density of the soils under vegetable cultivation varied from 1.21-1.37 Mg m^{-3} with a mean value of 1.30 Mg m^{-3} and under buffer conditions it ranged from 1.23 to 1.41 Mg m^{-3} with a mean value of 1.32 Mg m^{-3}. Bagwar village of Bhoranj block recorded lowest and Khagal village of

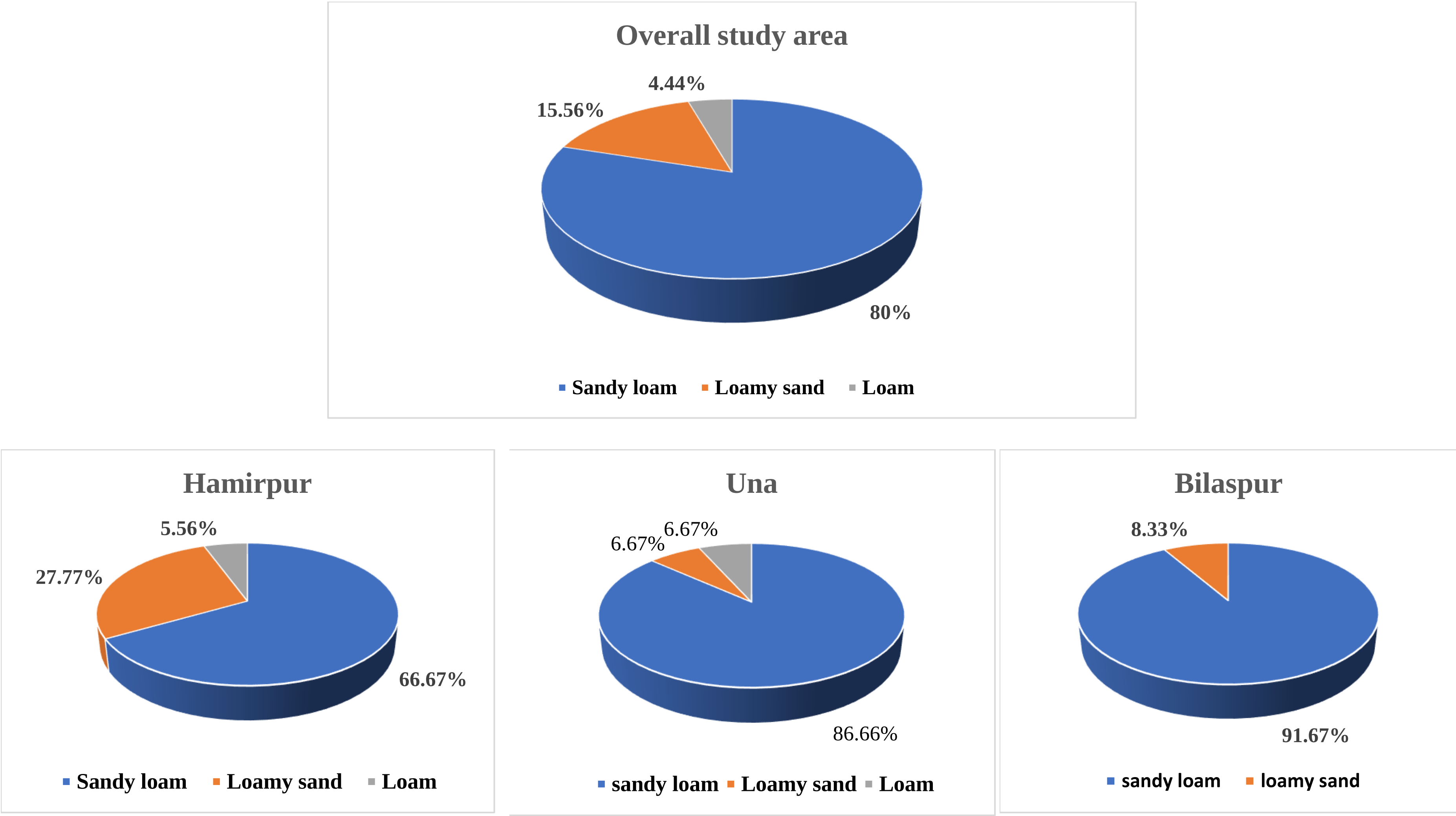


Figure 4.1 Percentage distribution of textural class of soil

Hamirpur block recorded highest bulk density of soil under vegetable cultivation. The highest bulk density under buffer condition was observed in Bhalana and Kangroo village of Sujanpur and Bamson block, respectively, while lowest was observed in village Bagwar village of Bhoranj block. Among different blocks of Hamirpur district, highest mean bulk density under cultivated and buffer condition were recorded in Bamson block (1.35 and 1.36 Mg m^{-3}, respectively) followed by Hamirpur block (1.32 and 1.35 Mg m^{-3}, respectively) and lowest bulk density was recorded in Bhoranj block (1.24 and 1.25 Mg m^{-3}, respectively).

In Una district, the bulk density of soils under vegetable cultivation varied from 1.20 to 1.43 Mg m^{-3} with a mean value of 1.32 Mg m^{-3}, whereas, in buffer conditions it ranged from 1.26 to 1.46 Mg m^{-3} with a mean value of 1.35 Mg m^{-3}. The highest bulk density values under cultivated and buffer conditions were observed in Heera Nagar village of Amb block, while the lowest was recorded in Bhadsali village of Haroli block. On comparing different blocks of Una district, it was observed that under cultivated conditions, Amb block recorded highest mean bulk density (1.38 Mg m^{-3}) followed by Bangana block (1.33 Mg m^{-3}), Gagret (1.32 Mg m^{-3}) and Una block (1.32 Mg m^{-3}) while lowest bulk density was observed in Haroli Block (1.23 Mg m^{-3}). Almost similar trend of bulk density of different blocks was observed for buffer condition.

In Bilaspur district, soil bulk density varied from 1.24 to 1.41 Mg m^{-3} with a mean value of 1.31 Mg m^{-3}, whereas, in buffer conditions it ranged between 1.29 to 1.45 Mg m^{-3} with a mean value of 1.35 Mg m^{-3}. The highest bulk density values under cultivated and buffer conditions were recorded in Samari village of Bilaspur Sadar block and lowest in Loharwin village of Ghumarwin block. Bilaspur Sadar, Ghumarwin, Jhanduta and Shri Naina Devi Ji blocks recorded 1.36, 1.27, 1.30 and 1.29 Mg m^{-3} mean bulk density values, respectively under cultivated conditions and 1.39, 1.33, 1.34 and 1.32 Mg m^{-3} mean bulk density values, respectively under buffer conditions.

In overall study area, the bulk density of soils under vegetable cultivation varied from 1.20 to 1.43 Mg m^{-3} with a mean of 1.31 Mg m^{-3} and under buffer conditions it ranged from 1.23 to 1.46 Mg m^{-3} with a mean of 1.34 Mg m^{-3}. Among all the sites of study area under cultivated conditions, Bhadsali village in Haroli block of Una district was found to be have the lowest bulk density of 1.20 Mg m^{-3} while, Heera Nagar village in Amb block of Una district recorded the highest bulk density of 1.43 Mg m^{-3}. Among different districts, Una district recorded the highest mean bulk density (1.32 Mg m^{-3}) under cultivated condition, whereas lowest mean bulk density was observed in district Hamirpur (1.30 Mg m^{-3}). Overall average bulk density under cultivated conditions was found lower (1.31 Mg m^{-3}) as compared to buffer conditions (1.34 Mg m^{-3}). The CV of 4.59 and 4.48 for cultivated and buffer conditions, respectively indicates that it varied spatially. Similar range of bulk density was also observed by Kyandiah (2012), Chandel *et al.* (2017) and Shabnam (2018) for soils of different districts of Himachal Pradesh. In general, bulk density value less than 1.50 Mg m^{-3} is taken as low. Therefore, most of the sites of the present study had low bulk density which means that the soils were less compact and hence good for the production of vegetables. Lower bulk density values of all of the sites under vegetable production as compared to buffer conditions might be attributed to higher organic carbon contents observed under cultivated conditions as well the role of intensive management (tillage operations, frequent applications of higher amount of organic manures and chemical fertilizers) and consequently better microbial activities. Soil aggregations are the other reasons for the lower values of bulk density under cultivated conditions as compared to buffer conditions as observed in the present study.

iii. Maximum water holding capacity

An insight into the data in table 4.2 revealed that in Hamirpur district the maximum water holding capacity of the soils under vegetable cultivation varied from 42.3-51.3 per cent with a mean value of 45.5 per cent and under buffer conditions it ranged from 40.3 to 49.5 per cent with a mean value of 43.5 per cent. Bagwar village of Bhoranj block recorded highest and Salan village of Bhijari block recorded lowest maximum water holding capacity of soil under vegetable cultivation. The highest maximum water holding capacity under buffer condition was observed in Bagwar village of Bhoranj block while lowest was observed in village Bhalana village of Sujanpur block. On comparing different blocks of Hamirpur district it was observed that under cultivated conditions, Bhoranj block recorded highest maximum water holding capacity (48.0 %) followed by Sujanpur block (46.3 %) while lowest maximum water holding capacity was observed in Bamson Block (42.9 %). Almost similar trend of maximum water holding capacity of different blocks was observed for buffer condition.

In Una district, the maximum water holding capacity of soils under vegetable cultivation varied from 40.2 to 50.2 per cent with a mean value of 44.7 per cent, whereas, in buffer conditions it ranged from 37.2 to 48.7 per cent with a mean value of 42.2 per cent. The highest maximum water holding capacity values under cultivated and buffer conditions were

Table 4.2 Status of bulk density and maximum water holding capacity (MWHC) of soils under cultivated and buffer conditions

Block	Sites	Bulk Density ($Mg\ m^{-3}$)		MWHC (%)	
		Cultivated	Buffer	Cultivated	Buffer
District- Hamirpur					
Bamson	Gulela	1.35	1.36	42.7	40.3
	Kangroo	1.36	1.41	42.3	41.2
	Halana	1.35	1.32	43.7	42.5
	Mean	1.35	1.36	42.9	41.3
Bhoranj	Jhandwin Changria	1.28	1.28	45.5	44.9
	Ghamarwin	1.24	1.25	47.3	45.2
	Bagwar	1.21	1.23	51.3	49.5
	Mean	1.24	1.25	48.0	46.5
Bijhari	Bilkar Kahan	1.29	1.32	47.5	45.3
	Patera	1.28	1.31	45.6	44.7
	Salan	1.33	1.36	42.3	40.5
	Mean	1.30	1.33	45.1	43.5
Hamirpur	Kakru	1.28	1.34	46.3	43.5
	Karahlar	1.32	1.32	43.7	41.3
	Khagal	1.37	1.40	44.5	41.9
	Mean	1.32	1.35	44.8	42.2
Nadaun	Bharmoti	1.32	1.37	44.3	42.7
	Mewli	1.22	1.24	48.7	46.3
	Kohla	1.31	1.33	43.6	41.5
	Mean	1.28	1.31	45.5	43.5
Sujanpur	Bhalana	1.35	1.41	43.6	40.3
	Tikkar	1.26	1.28	49.5	47.1
	Chaunki	1.27	1.31	45.8	44.7
	Mean	1.29	1.33	46.3	44.0
District Mean		1.30	1.32	45.5	43.5
District Range		1.21-1.37	1.23-1.41	42.3-51.3	40.3-49.5
District- Una					
Amb	Amb	1.33	1.38	45.7	42.5
	Pramb	1.37	1.38	44.7	42.2
	Heera Nagar	1.43	1.46	40.2	37.2
	Mean	1.38	1.41	43.5	40.6
Bangana	Malangar	1.30	1.34	42.7	38.9
	Amrera	1.41	1.46	40.5	37.5
	Surda	1.29	1.35	46.8	43.4

	Mean	1.33	1.38	43.3	39.9
Gagret	Dolatpur	1.25	1.31	47.5	44.6
	Ghanari	1.31	1.34	42.3	41.1
	Deoli	1.41	1.43	42.8	38.7
	Mean	1.32	1.36	44.2	41.5
Haroli	Shatarpur	1.22	1.27	48.7	44.9
	Ghaluwal	1.28	1.30	45.6	43.8
	Bhadsali	1.20	1.26	50.2	48.7
	Mean	1.23	1.28	48.2	45.8
Una	Fatehpur	1.32	1.35	42.3	42.1
	Sasan	1.30	1.31	46.5	43.0
	Lal Singhi	1.34	1.36	44.7	43.8
	Mean	1.32	1.34	44.5	43.0
District Mean		1.32	1.35	44.7	42.2
District Range		1.20-1.43	1.26-1.46	40.2-50.2	37.2-48.7
District- Bilaspur					
Bilaspur Sadar	Manman	1.32	1.33	44.7	41.1
	Panjel Khurd	1.35	1.40	45.2	42.8
	Samari	1.41	1.45	41.2	40.7
	Mean	1.36	1.39	43.7	41.5
Ghumarwin	Bhadrog	1.27	1.34	47.8	45.2
	Jahri	1.30	1.36	47.2	44.8
	Loharwin	1.24	1.29	49.8	46.7
	Mean	1.27	1.33	48.3	45.6
Jhanduta	Galian	1.26	1.31	54.2	51.8
	Behran	1.29	1.34	47.5	44.6
	Amroha	1.35	1.37	43.9	42.5
	Mean	1.30	1.34	48.5	46.3
Shri Naina Devi Ji	Dabheta	1.32	1.34	45.2	43.5
	Kutahla	1.25	1.30	47.6	44.3
	Kulah	1.30	1.33	45.2	42.3
	Mean	1.29	1.32	46.0	43.4
District Mean		1.31	1.35	46.6	44.2
District Range		1.24-1.41	1.29-1.45	41.2-54.2	40.7-51.8
Overall Mean		1.31	1.34	45.5	43.2
Overall Range		1.20-1.43	1.23-1.46	40.2-54.2	37.2-51.8
Standard Error		0.05	0.05	0.43	0.44
CV		4.59	4.48	6.41	6.75
Standard Deviation		0.06	0.06	2.92	2.92

observed in Bhadsali village of Haroli block, while the lowest was recorded in Heera Nagar village of Amb block. Among different blocks of Una district, highest mean maximum water holding capacity under cultivated and buffer condition were recorded in Haroli block (48.2 and 45.8 %, respectively) and lowest were recorded in Bangana block (43.3 and 39.9 %, respectively).

In Bilaspur district, maximum water holding capacity of soils under cultivated conditions varied from 41.2 to 54.2 per cent with a mean value of 46.6 per cent, whereas, in buffer conditions it ranged between 40.7 to 51.8 per cent with a mean value of 44.2 per cent. The highest mean maximum water holding capacity values under cultivated and buffer conditions were recorded in Galian village of Jhanduta block and lowest in Samari village of Bilaspur Sadar block. Bilaspur Sadar, Ghumarwin, Jhanduta and Shri Naina Devi Ji blocks recorded 43.7, 48.3, 48.5 and 46.0 per cent mean maximum water holding capacity values, respectively under cultivated conditions and 41.5, 45.6, 46.3 and 43.4 per cent mean maximum water holding capacity values, respectively under buffer conditions.

Maximum water holding capacity in the overall studied area varied from 40.2 to 54.2 per cent with a mean value of 45.5 per cent under vegetable cultivation and under buffer conditions it ranged from 37.2 to 51.8 per cent with a mean value of 43.2 per cent. Among all the villages under cultivated conditions, Heera Nagar village in Amb block of Una district was found to have the lowest maximum water holding capacity of 40.2 per cent while Galian village in Jhanduta block of Bilaspur district had the highest maximum water holding capacity of 54.2 per cent. Among districts, Bilaspur district recorded the highest mean maximum water holding capacity (46.6 %), whereas lowest mean maximum water holding capacity was observed in district Una (44.7 %). The CV of 6.41 under cultivated conditions of vegetable production indicates that it varied spatially. Average maximum water holding capacity was found comparatively higher (45.5 %) under cultivated conditions as compared to buffer conditions (43.2 %). This might be due to the reasons that soils under buffer conditions were compact as compared to cultivated conditions. Similar range of maximum water holding capacity was also observed by Shabnam (2018) and Kumar (2019) in soils of different areas of Himachal Pradesh. Maximum water holding capacity of soil is influenced by many factors especially soil texture, organic matter and structure of the soil. Increase in maximum water holding capacity under the cultivation conditions might be attributed to stable aggregates and better structure as compared to buffer conditions. Higher maximum water holding capacity in some areas may be due to less bulk density and more organic matter content coupled with higher percentage of clay in soil and vegetable based cropping system which enhanced the available water.

4.1.2 Chemical properties

i. Soil pH

A perusal of data in table 4.3 revealed that pH of the soils of Hamirpur district under vegetable cultivation varied from 6.50-7.12 with a mean value of 6.84 and under buffer conditions it ranged from 6.47 to 7.08 with a mean value of 6.80. Gulela village of Bamson block recorded lowest and Bharmoti village of Nadaun block recorded highest pH of soil under vegetable cultivation. Under buffer conditions Bharmoti village of Nadaun block recorded the highest and Jhandwin Changria village of Bhoranj block recorded the lowest soil pH. Among different blocks of Hamirpur district, highest mean soil pH under cultivated and buffer condition were recorded in Sujanpur block (7.06 and 6.97, respectively) followed by Nadaun block (6.97 and 6.93, respectively) and lowest pH was recorded in Bamson block (6.60 and 6.56, respectively).

In Una district, the pH of soils under vegetable cultivation varied from 6.85 to 7.64 with a mean value of 7.27, whereas, in buffer conditions it ranged from 6.80 to 7.59 with a mean value of 7.23. The highest pH values under cultivated and buffer conditions were observed in Ghaluwal village of Haroli block, while the lowest was recorded in Amrera village of Bangana block. On comparing different blocks of Una district, it was observed that under cultivated conditions, Haroli block recorded highest soil pH (7.56) followed by Amb block (7.40), Gagret (7.24) and Una block (7.19), while lowest soil pH was observed in Bangana Block (6.96). Almost similar trend of pH of different blocks was observed for buffer condition.

In Bilaspur district, soil pH varied from 6.84 to 7.49 with a mean value of 7.21, whereas, in buffer conditions it ranged between 6.75 to 7.41 with a mean value of 7.15. The highest soil pH values under cultivated condition were recorded in Kutahla village of Shri Naina Devi Ji block and lowest in Galian village of Jhanduta block. Bilaspur Sadar, Ghumarwin, Jhanduta and Shri Naina Devi Ji blocks recorded 7.36, 7.11, 7.05 and 7.33 mean soil pH values, respectively under cultivated conditions and 7.31, 7.05, 6.98 and 7.24, respectively under buffer conditions.

The pH of the soils under vegetable cultivation varied from 6.50 to 7.64 with a mean value of 7.08, whereas, in buffer conditions it ranged from 6.47 to 7.59 with a mean value of

7.03 in the overall studied area. The highest pH value under cultivated conditions was observed in Ghaluwal village (7.64) of Haroli block of Una district, while the lowest pH was recorded in Gulela village (6.50) of Bamson block of Hamirpur district. Among districts, Una district recorded the highest mean soil pH value (7.27), whereas lowest mean pH value was observed in district Hamirpur (6.84). Overall mean soil pH was found to be higher under cultivated conditions (7.08) as compared to buffer conditions (7.03). The CV of 4.11 under vegetable cultivation and 4.08 under buffer conditions indicates that it varied spatially. The result trend was in line with the findings of Sharma and Dogra (2011) and Suri (2018) in different areas of Himachal Pradesh. The lower pH in few locations of the study areas might be due to low degree of base saturation in the soil. Comparatively higher pH under cultivated conditions might be due to reduction in leaching of bases and moderating effect of organic matter as it decreases the activity of exchangeable Al^{3+} ions in soil solution due to chelation effect of organic molecules (Hue 1992) and formation of alumino-phosphate complexes, respectively. Similar results of moderating effect of FYM on soil pH have also been reported by Pathak *et al.* (2005) and Urkurkar *et al.* (2010). However, quite low pH values recorded at some sites may be ascribed mainly to use of acid forming fertilizers, parent materials, higher rainfall and organic matter content of such soils.

ii. Electrical conductivity

A scrutiny of data presented in table 4.3 revealed that in Hamirpur district the electrical conductivity of soils under vegetable cultivation varied from 0.155-0.225 dS m^{-1} with a mean value of 0.194 dS m^{-1} and under buffer conditions it ranged from 0.142 to 0.245 dS m^{-1} with a mean value of 0.183 dS m^{-1}. Mewli village of Nadaun block recorded highest and Kangroo village of Bamson block recorded lowest electrical conductivity of soil under vegetable cultivation. The highest electrical conductivity under buffer condition was observed in Mewli village of Nadaun block while lowest was observed in Jhandwin Changria village of Bhoranj block. On comparing different blocks of Hamirpur district it was observed that under cultivated conditions, Nadaun block recorded highest mean electrical conductivity (0.204 dS m^{-1}) while lowest mean electrical conductivity was observed in Bamson block (0.177 dS m^{-1}). Almost similar trend of mean electrical conductivity for different blocks was observed for buffer condition.

The electrical conductivity of soils under vegetable cultivation in Una district varied from 0.164 to 0.287 dS m^{-1} with a mean value of 0.217 dS m^{-1}, whereas, in buffer conditions it ranged from 0.156 to 0.256 dS m^{-1} with a mean value of 0.197 dS m^{-1}. The highest

Table 4.3 Status of pH and electrical conductivity (dS m^{-1}) of soils under cultivated and buffer conditions

Block	Sites	pH		EC (dS m^{-1})	
		Cultivated	Buffer	Cultivated	Buffer
District- Hamirpur					
Bamson	Gulela	6.50	6.48	0.167	0.147
	Kangroo	6.58	6.55	0.155	0.150
	Halana	6.71	6.66	0.208	0.194
	Mean	6.60	6.56	0.177	0.164
Bhoranj	Jhandwin Changria	6.51	6.47	0.157	0.142
	Ghamarwin	6.82	6.70	0.212	0.198
	Bagwar	6.63	6.58	0.212	0.197
	Mean	6.65	6.58	0.194	0.179
Bijhari	Bilkar Kahan	6.72	6.66	0.178	0.163
	Patera	6.94	7.03	0.201	0.19
	Salan	6.97	6.95	0.217	0.197
	Mean	6.88	6.88	0.199	0.183
Hamirpur	Kakru	7.05	6.97	0.205	0.195
	Karahlar	6.67	6.72	0.183	0.174
	Khagal	6.90	6.88	0.198	0.187
	Mean	6.87	6.86	0.195	0.185
Nadaun	Bharmoti	7.12	7.08	0.185	0.191
	Mewli	6.89	6.84	0.225	0.245
	Kohla	6.91	6.87	0.203	0.185
	Mean	6.97	6.93	0.204	0.207
Sujanpur	Bhalana	7.10	6.97	0.213	0.189
	Tikkar	6.97	6.90	0.156	0.148
	Chaunki	7.11	7.04	0.209	0.194
	Mean	7.06	6.97	0.193	0.177
District Mean		6.84	6.80	0.194	0.183
District Range		6.50-7.12	6.47-7.08	0.155-0.225	0.142-0.245
District- Una					
Amb	Amb	7.39	7.37	0.212	0.207
	Pramb	7.22	7.18	0.232	0.214
	Heera Nagar	7.60	7.54	0.201	0.192
	Mean	7.40	7.36	0.215	0.204
Bangana	Malangar	6.91	6.87	0.287	0.256
	Amrera	6.85	6.80	0.198	0.178
	Surda	7.12	7.10	0.209	0.187
	Mean	6.96	6.92	0.231	0.207

Gagret	Dolatpur	7.25	7.20	0.211	0.194
	Ghanari	7.27	7.22	0.187	0.178
	Deoli	7.21	7.19	0.195	0.184
	Mean	7.24	7.20	0.198	0.185
Haroli	Shatarpur	7.45	7.38	0.245	0.211
	Ghaluwal	7.64	7.59	0.284	0.241
	Bhadsali	7.60	7.55	0.208	0.187
	Mean	7.56	7.51	0.246	0.213
Una	Fatehpur	7.25	7.21	0.202	0.178
	Sasan	7.14	7.08	0.213	0.185
	Lal Singhi	7.18	7.11	0.164	0.156
	Mean	7.19	7.13	0.193	0.173
District Mean		7.27	7.23	0.217	0.197
District Range		6.85-7.64	6.80-7.59	0.164-0.287	0.156-0.256
District- Bilaspur					
Bilaspur Sadar	Manman	7.40	7.38	0.231	0.204
	Panjel Khurd	7.22	7.14	0.195	0.173
	Samari	7.46	7.41	0.245	0.221
	Mean	7.36	7.31	0.224	0.199
Ghumarwin	Bhadrog	6.97	6.88	0.164	0.157
	Jahri	7.12	7.06	0.201	0.241
	Loharwin	7.24	7.21	0.221	0.198
	Mean	7.11	7.05	0.195	0.199
Jhanduta	Galian	6.84	6.75	0.174	0.154
	Behran	7.32	7.28	0.235	0.212
	Amroha	6.98	6.91	0.154	0.124
	Mean	7.05	6.98	0.188	0.163
Shri Naina Devi Ji	Dabheta	7.22	7.14	0.217	0.189
	Kutahla	7.49	7.36	0.245	0.215
	Kulah	7.29	7.22	0.195	0.181
	Mean	7.33	7.24	0.219	0.195
District Mean		7.21	7.15	0.206	0.189
District Range		6.84-7.49	6.75-7.41	0.154-0.245	0.124-0.241
Overall Mean		7.08	7.03	0.205	0.189
Overall Range		6.50-7.64	6.47-7.59	0.154-0.287	0.124-0.256
Standard Error		0.11	0.11	0.07	0.07
CV		4.11	4.08	14.66	15.87
Standard Deviation		0.29	0.29	0.03	0.03

electrical conductivity values under cultivated and buffer conditions were observed in Malangar village of Bangana block, while the lowest was recorded in Lal Singhi village of Una block. Among different blocks of Una district, highest mean electrical conductivity under cultivated and buffer condition were recorded in Haroli block (0.246 and 0.213 dS m^{-1}, respectively) and lowest were recorded in Una block (0.193 and 0.173 dS m^{-1}, respectively).

Electrical conductivity in Bilaspur district, varied from 0.154 to 0.245 dS m^{-1} with a mean value of 0.206 dS m^{-1}, whereas, in buffer conditions it ranged between 0.124 to 0.241 dS m^{-1} with a mean value of 0.189 dS m^{-1}. The highest electrical conductivity value under cultivated conditions was recorded in Samari village of Bilaspur Sadar block and Kuthala village of Shri Naina Devi Ji block, while lowest electrical conductivity was recorded in Amroha village of Jhanduta block. Bilaspur Sadar, Ghumarwin, Jhanduta and Shri Naina Devi Ji blocks recorded electrical conductivity values of 0.224, 0.195, 0.188 and 0.219 dS m^{-1}, respectively under cultivated conditions and 0.199, 0.199, 0.163 and 0.195 dS m^{-1} electrical conductivity values, respectively under buffer conditions.

In overall study area, electrical conductivity varied from 0.154 to 0.287 dS m^{-1} with a mean value of 0.205 dS m^{-1} under vegetable cultivation, whereas in buffer conditions it varied from 0.124 to 0.256 dS m^{-1} with a mean of 0.189 dS m^{-1}. Among districts, Una district recorded the highest mean electrical conductivity (0.217 dS m^{-1}), whereas lowest mean electrical conductivity was observed in district Hamirpur (0.194 dS m^{-1}). In overall, Malangar village in Bangana block of Una district was found to have the highest electrical conductivity of 0.287 dS m^{-1} while Amroha village in Jhanduta block of Bilaspur district recorded the lowest electrical conductivity of 0.154 dS m^{-1} under cultivated conditions. Under buffer conditions Malangar village (0.256 dS m^{-1}) of Bangana block of Una district recorded the highest while Amroha village (0.124 dS m^{-1}) in Jhanduta block of Bilaspur district recorded the lowest electrical conductivity of soil. The CV of 14.66 under cultivated condition and 15.87 under buffer conditions indicates that it varied spatially. Average electrical conductivity was found comparatively higher (0.205 dS m^{-1}) under cultivated conditions over buffer conditions (0.189 dS m^{-1}). The data on electrical conductivity of the studied soils revealed that all the sites do not have any salinity problem. The results showed that all the EC values were under normal range (<1.0). The normal EC range of the soil is attributed to the leaching of salts to lower depths due to continuous tillage practices, cropping, very high rainfall as well as water applied for irrigation by local means (flood irrigation, *Kuhl system* etc). The result trend was in line with the findings of Chandel *et al.* (2017), Suri (2018) and Arshad (2020) for soils of different districts of Himachal Pradesh.

iii. Organic carbon

Critical analysis of the data in table 4.4 revealed that in Hamirpur district the organic carbon content of the soils under vegetable cultivation varied from 6.8 to17.2 g kg^{-1} with a mean value of 10.8 g kg^{-1} and under buffer conditions it ranged from 4.5 to 7.0 g kg^{-1} with a mean value of 5.6 g kg^{-1}. Bilkar Kahan village of Bijhari block recorded highest and Bhalana village of Sujanpur block recorded lowest organic carbon content of soil under vegetable cultivation. Almost similar trend of organic carbon for different villages of Hamirpur district was observed for buffer conditions. Bamson, Bhoranj, Bijhari, Hamirpur, Nadaun and Sujanpur blocks recorded mean organic carbon content of 12.5, 10.5, 15.6, 9.0, 8.4 and 9.0 g kg^{-1}, respectively under cultivated conditions, whereas 6.0, 5.6, 5.6, 5.1, 5.0 and 5.1 g kg^{-1}, respectively under buffer conditions.

In Una district, the organic carbon content of soils under vegetable cultivation varied from 6.9 to 13.5 g kg^{-1} with a mean value of 9.9 g kg^{-1}, whereas, in buffer conditions it ranged from 4.8 to 6.3 g kg^{-1} with a mean value of 5.5 g kg^{-1}. The highest organic carbon content under cultivated and buffer conditions were observed in Shatarpur village of Haroli block, while the lowest was recorded in Deoli village of Gagret block. Among different blocks of Una district, highest mean organic carbon under cultivated conditions was recorded in Haroli block (12.3 g kg^{-1}) and lowest organic carbon content was recorded in Gagret block (8.1 g kg^{-1}).

Organic carbon content in the soils of Bilaspur district under cultivated conditions varied from 9.3 to 14.5 g kg^{-1} with a mean value of 12.0 g kg^{-1}, whereas, in buffer conditions it ranged between 5.2 to 6.5 g kg^{-1} with a mean value of 5.9 g kg^{-1}. The highest organic carbon content under cultivated and buffer conditions were recorded in Loharwin village of Ghumarwin block and lowest in Manman village of Bilaspur Sadar block. Bilaspur Sadar, Ghumarwin, Jhanduta and Shri Naina Devi Ji blocks recorded 10.0, 12.7, 13.1 and 12.2 g kg^{-1} mean organic carbon content, respectively under cultivated conditions and 5.4, 6.0, 6.2 and 5.9 g kg^{-1} mean organic carbon content, respectively under buffer conditions.

Organic carbon contents in soils of the overall studied area, varied from 6.8 to 17.2 g kg^{-1} with a mean value of 10.8 g kg^{-1} under cultivated conditions. Whereas, under buffer conditions organic carbon content ranged from 4.5 to 7.0 g kg^{-1} with a mean value of 5.6 g

Table 4.4 Status of soil organic carbon (g kg^{-1}) of soils under cultivated and buffer conditions

Block	Sites	Organic carbon (g kg^{-1})	
		Cultivated	Buffer
District- Hamirpur			
Bamson	Gulela	12.3	6.1
	Kangroo	13.2	6.2
	Halana	12.0	5.8
	Mean	12.5	6.0
Bhoranj	Jhandwin Changria	9.3	5.2
	Ghamarwin	9.8	5.4
	Bagwar	12.3	6.3
	Mean	10.5	5.6
Bijhari	Bilkar Kahan	17.2	7.0
	Patera	14.3	6.6
	Salan	15.3	6.7
	Mean	15.6	5.6
Hamirpur	Kakru	10.2	5.6
	Karahlar	8.7	5.0
	Khagal	8.0	4.7
	Mean	9.0	5.1
Nadaun	Bharmoti	7.5	4.6
	Mewli	9.0	5.3
	Kohla	8.7	5.2
	Mean	8.4	5.0
Sujanpur	Bhalana	6.8	4.5
	Tikkar	10.5	5.6
	Chaunki	9.7	5.3
	Mean	9.0	5.1
District Mean		10.8	5.6
District Range		6.8-17.2	4.5-7.0
District- Una			
Amb	Amb	11.2	5.7
	Pramb	9.0	5.4
	Heera Nagar	8.5	5.3
	Mean	9.6	5.5
Bangana	Malangar	10.5	5.6
	Amrera	9.7	5.3
	Surda	10.9	5.7

	Mean	10.4	5.5
Gagret	Dolatpur	10.4	5.3
	Ghanari	7.1	4.9
	Deoli	6.9	4.8
	Mean	8.1	5.0
Haroli	Shatarpur	13.5	6.3
	Ghaluwal	11.5	5.6
	Bhadsali	12.0	6.2
	Mean	12.3	6.0
Una	Fatehpur	10.5	6.2
	Sasan	9.3	5.4
	Lal Singhi	8.2	5.1
	Mean	9.3	5.6
District Mean		9.9	5.5
District Range		6.9-13.5	4.8-6.3
	District- Bilaspur		
Bilaspur Sadar	Manman	9.3	5.2
	Panjel Khurd	11.0	5.7
	Samari	9.8	5.3
	Mean	10.0	5.4
Ghumarwin	Bhadrog	12.3	5.8
	Jahri	11.2	5.6
	Loharwin	14.5	6.5
	Mean	12.7	6.0
Jhanduta	Galian	14.5	6.4
	Behran	13.6	6.2
	Amroha	11.3	5.9
	Mean	13.1	6.2
Shri Naina Devi Ji	Dabheta	12.7	6.0
	Kutahla	11.5	5.6
	Kulah	12.5	6.0
	Mean	12.2	5.9
District Mean		12.0	5.9
District Range		9.3-14.5	5.2-6.5
Overall Mean		10.8	5.6
Overall Range		6.8-17.2	4.5-7.0
Standard Error		0.71	0.24
CV		21.66	10.27
Standard deviation		2.35	0.58

kg^{-1}. Among various sites selected for the study under cultivated and buffer conditions, Bilkar Kahan village in Bijhari block of Hamirpur district (17.2 and 7.0 g kg^{-1}) recorded the highest organic carbon content, whereas Bhalana village in Sujanpur block of Hamirpur district recorded the lowest organic carbon content (6.8 and 4.5 g kg^{-1}). Among districts, Bilaspur district recorded the highest mean organic carbon content (12.0 g kg^{-1}), whereas lowest mean organic carbon content was observed in district Una (9.9 g kg^{-1}). The CV of 21.66 under cultivated conditions of vegetable production and 10.27 under buffer conditions indicates that it varied spatially. Mean organic carbon content of soil was found comparatively higher (10.8 g kg^{-1}) under cultivated conditions as compared to buffer conditions (5.6 g kg^{-1}). The majority of the soil samples from cultivated conditions of the study areas fall into the high (91 %) soil fertility class of organic carbon while rest (9%) fall under medium class as shown in figure 2, which could be attributed to regular addition of FYM and plant residues by the vegetable growers. These results are in accordance with the findings of Pal *et al.* (2013) and Biswas *et al.* (2017) in different districts of Himachal Pradesh.

iv. Available nitrogen

The data on the available nitrogen content of the soil under different conditions and sites is presented in table 4.5. Perusal of the data revealed that available nitrogen content in soils of Hamirpur district under vegetable cultivation varied from 245.3-416.6 kg ha^{-1} with a mean value of 315.2 kg ha^{-1} and under buffer conditions it ranged from 188.3 to 290.8 kg ha^{-1} with a mean value of 241.0 kg ha^{-1}. Bilkar Kahan village of Bijhari block recorded highest and Ghamarwin village of Bhoranj block recorded lowest available nitrogen content under cultivated conditions. Under buffer conditions Bilkar Kahan village of Bijhari block recorded highest and Bharmoti village of Nadaun block recorded lowest available nitrogen content. Among different blocks of Hamirpur district, highest mean available nitrogen under cultivated and buffer condition was recorded in Bijhari block (379.3 and 282.4 kg ha^{-1}, respectively) and lowest available nitrogen was recorded in Bhoranj block (261.3 and 209.0 kg ha^{-1}, respectively).

In Una district, the available nitrogen content of soils under vegetable cultivation varied from 257.6 to 376.3 kg ha^{-1} with a mean value of 318.0 kg ha^{-1}, whereas, in buffer conditions it ranged from 178.5 to 312.3 kg ha^{-1} with a mean value of 248.4 kg ha^{-1}. The highest available nitrogen values under cultivated conditions were observed in Pramb village of Amb block, Malangar village of Bangana block and Shatarpur village of Haroli block, while the lowest was recorded in Lal Singhi village of Una block. On comparing different blocks of

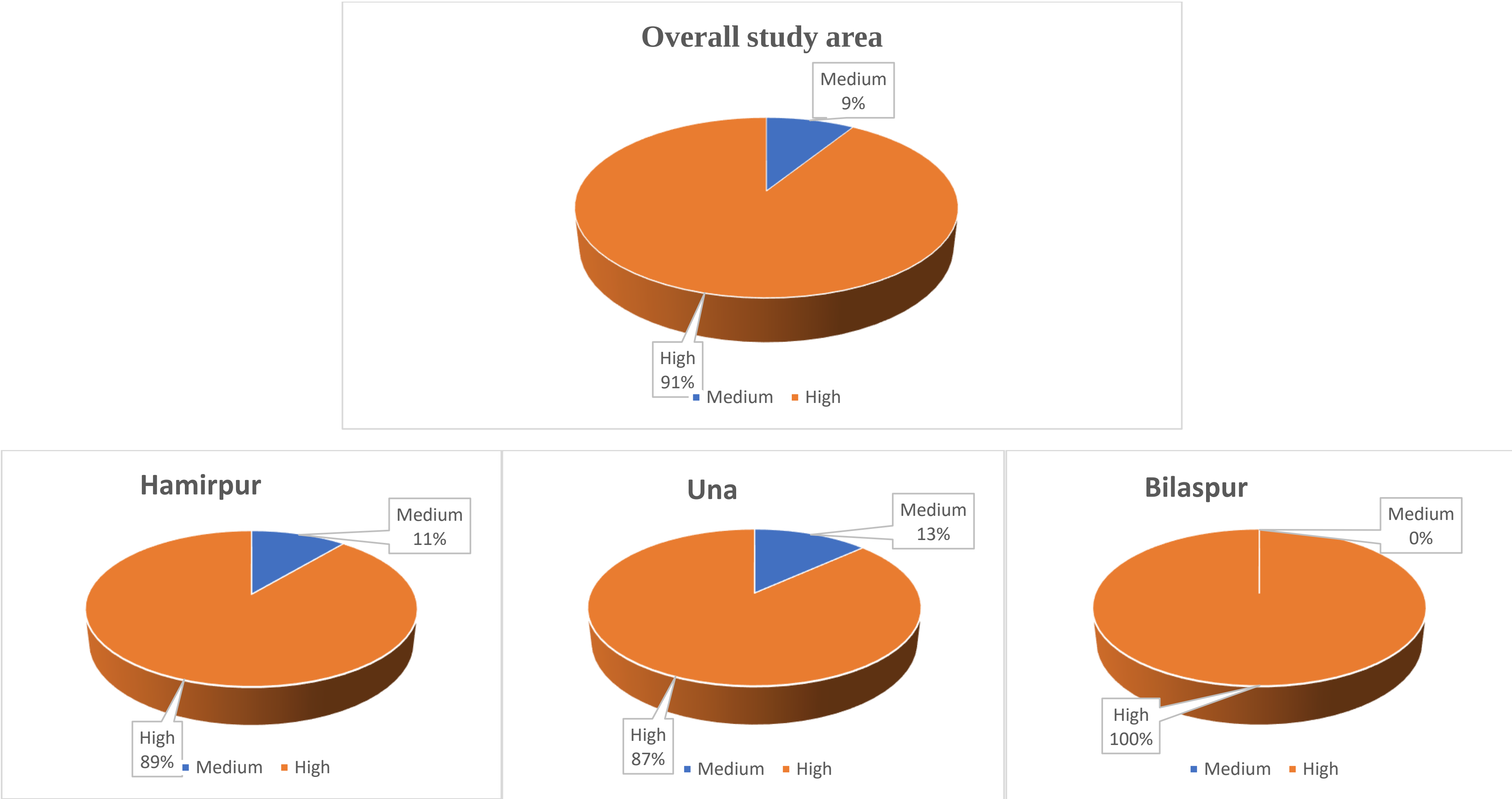


Figure 4.2 Percentage distribution of organic carbon

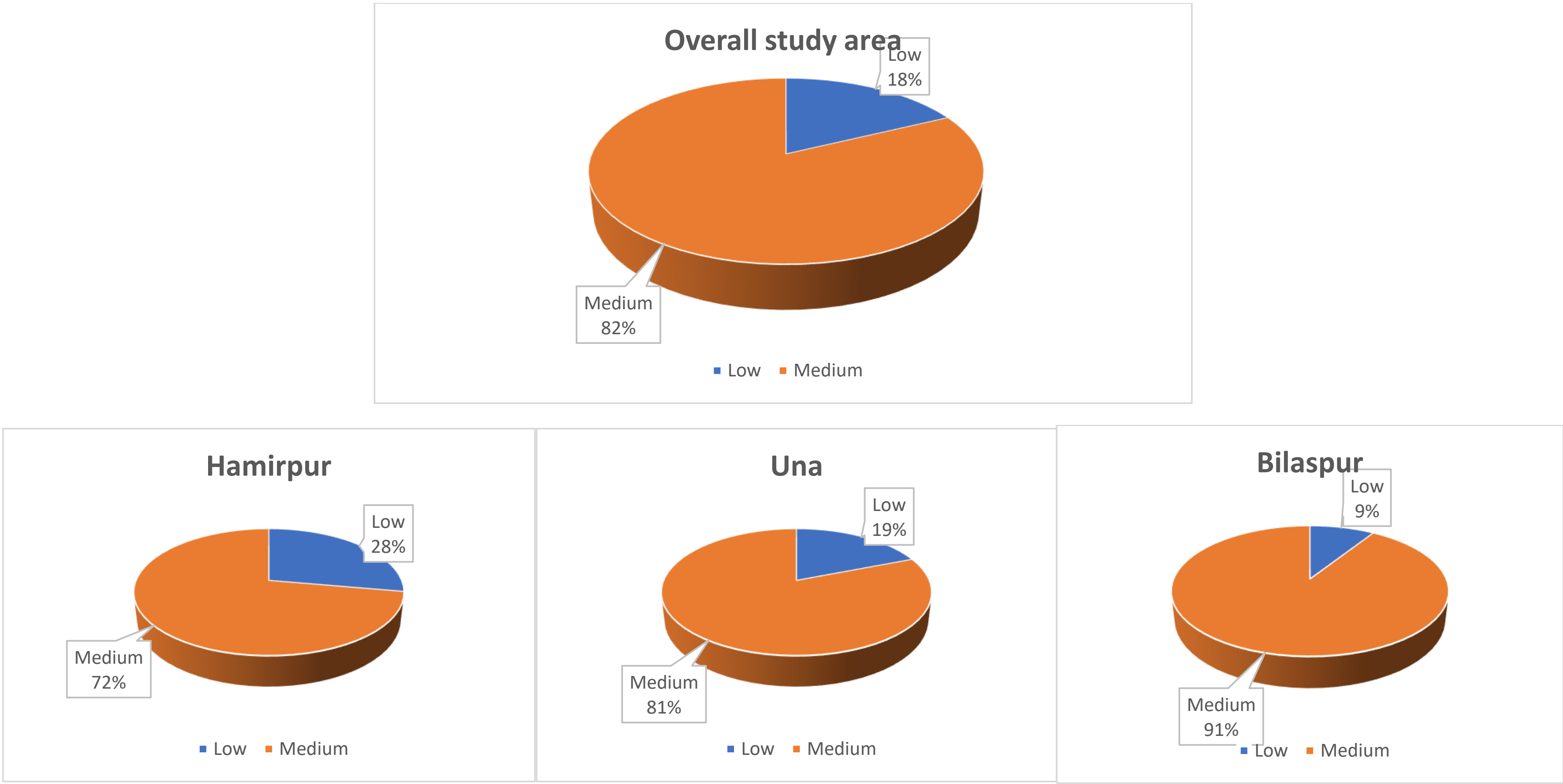


Figure 4.3 Percentage distribution of available nitrogen

Una district, it was observed that under cultivated conditions, Amb block recorded the highest mean available nitrogen content (337.8 kg ha^{-1}) followed by Bangana block (334.7 kg ha^{-1}), Haroli block (323.8 kg ha^{-1}) and Una block (298.8 kg ha^{-1}) while lowest available nitrogen content was observed in Gagret block (295.0 kg ha^{-1}).

Available nitrogen under cultivated conditions varied from 271.5 to 396.5 kg ha^{-1} with a mean value of 319.8 kg ha^{-1} in Bilaspur district whereas, in buffer conditions it ranged between 232.7 to 282.2 kg ha^{-1} with a mean value of 257.8 kg ha^{-1}. The highest available nitrogen content values under cultivated conditions were recorded in Dabheta village of Shri Naina Devi Ji block and lowest in Manman village of Bilaspur Sadar block. On comparing different blocks of Bilaspur district, it was observed that under cultivated conditions, Jhanduta block recorded highest available nitrogen (349.5 kg ha^{-1}) followed by Shri Naina Devi Ji block (330.4 kg ha^{-1}) and Ghumarwin block (310.3 kg ha^{-1}), while lowest available nitrogen was observed in Bilaspur Sadar block (289.1 kg ha^{-1}).

The available nitrogen content of soils under vegetable cultivation in the overall studied area varied from 245.3 to 416.6 kg ha^{-1} with a mean value of 317.4 kg ha^{-1}, whereas, in buffer conditions it ranged from 178.5 to 312.3 kg ha^{-1} with a mean value of 248.0 kg ha^{-1}. In overall, the highest available nitrogen value under cultivated conditions was observed in Bilkar Kahan village (416.6 kg ha^{-1}) of Bijhari block of Hamirpur district, while the lowest available nitrogen was recorded in Ghamarwin village (245.3 kg ha^{-1}) of Bhoranj block of Hamirpur district. Among districts, Bilaspur district recorded the highest mean available nitrogen value (319.8 kg ha^{-1}), whereas lowest mean available nitrogen value was observed in district Hamirpur (315.2 kg ha^{-1}). The CV of 14.45 under vegetable cultivation and 13.28 under buffer conditions indicates that it varied spatially. Overall mean available nitrogen content was found lower (248.0 kg ha^{-1}) under buffer conditions as compared to cultivated conditions (317.4 kg ha^{-1}) which might be due to application of organic and inorganic fertilizers in the cultivated fields and proper agricultural practices by the farmers. Available nitrogen content in the study area was recorded low to medium. Most of the soil samples of cultivated conditions had medium levels (82 %) of nitrogen content as shown in figure 3, which is attributable to the addition of urea, IFFCO and FYM by the vegetable growers. Sharma *et al*. (2007) also reported higher available nitrogen content in soil where manures were applied along with NPK fertilizers. Mishra *et al*. (2008) also reported a significant build up of nitrogen in soil receiving higher doses of NPK every year either alone or in combination with FYM. The results were in accordance with the findings of Biswas *et al.* (2017), Shabnam (2018) and Suri (2018) in different districts of Himachal Pradesh.

v. Available phosphorous

A scrutiny of data presented in table 4.5 revealed that available phosphorous content in soils of Hamirpur district under vegetable cultivation varied from 48.6 to 65.5 kg ha^{-1} with a mean value of 57.7 kg ha^{-1} and under buffer conditions it ranged from 17.8 to 24.2 kg ha^{-1} with a mean value of 21.3 kg ha^{-1}. Bharmoti village of Nadaun block recorded highest and Khagal village of Hamirpur block recorded lowest available phosphorous content in soil under vegetable cultivation. The highest and lowest available phosphorous under buffer condition was observed in Bagwar and Ghumarwin village, respectively of Bhoranj block. On comparing different blocks of Hamirpur district it was observed that under cultivated conditions, Nadaun block recorded highest mean available phosphorous (62.2 kg ha^{-1}) while lowest mean available phosphorous was observed in Sujanpur and Hamirpur block (56.2 kg ha^{-1}).

In Una district, the available phosphorous content of soils under cultivated conditions varied from 40.8 to 65.7 kg ha^{-1} with a mean value of 54.4 kg ha^{-1}, whereas, in buffer conditions it ranged from 17.3 to 24.0 kg ha^{-1} with a mean value of 21.5 kg ha^{-1}. The highest available phosphorous content under cultivated conditions was observed in Pramb village of Amb block, while the lowest was recorded in Ghaluwal village of Haroli block. Under buffer conditions highest available phosphorous content was recorded in Heera Nagar village of Amb block, while lowest was observed in Ghaluwal village of Haroli block. Among different blocks of Una district, highest mean available phosphorous content under cultivated conditions was recorded in Gagret block (61.2 kg ha^{-1}) and lowest available phosphorous content was recorded in Haroli block (43.5 kg ha^{-1}).

In Bilaspur district, available phosphorous content of soils varied from 40.2 to 65.3 kg ha^{-1} with a mean value of 52.5 kg ha^{-1}, whereas, in buffer conditions it ranged between 19.5 to 23.9 kg ha^{-1} with a mean value of 21.9 kg ha^{-1}. The highest available phosphorous content under cultivated conditions was recorded in Dabheta village of Shri Naina Devi Ji block and lowest in Samari village of Bilaspur Sadar block. Under buffer condition the highest available phosphorous content was observed in Bhadrog village of Ghumarwin block while lowest was observed in Behran village of Jhanduta block. Bilaspur Sadar, Ghumarwin, Jhanduta and Shri Naina Devi Ji blocks of Bilaspur district recorded 48.7, 52.7, 50.6 and 58.0 kg ha^{-1} mean

Table 4.5 Status of available nitrogen and phosphorous (kg ha^{-1}) of soils under cultivated and buffer conditions

Block	Sites	Available nitrogen (kg ha^{-1})		Available phosphorus (kg ha^{-1})	
		Cultivated	Buffer	Cultivated	Buffer
District- Hamirpur					
Bamson	Gulela	376.3	282.2	57.3	20.9
	Kangroo	398.2	250.8	55.8	23.9
	Halana	287.3	215.3	60.5	22.6
	Mean	353.9	249.4	57.9	22.5
Bhoranj	Jhandwin Changria	256.3	212.2	59.3	21.2
	Ghamarwin	245.3	198.3	52.1	17.8
	Bagwar	282.2	216.5	59.3	24.2
	Mean	261.3	209.0	56.9	21.1
Bijhari	Bilkar Kahan	416.6	290.8	64.3	21.5
	Patera	344.9	282.2	50.3	23.3
	Salan	376.5	274.3	55.9	21.6
	Mean	379.3	282.4	56.8	22.1
Hamirpur	Kakru	282.2	225.3	59.6	22.3
	Karahlar	289.6	247.3	60.5	23.1
	Khagal	351.3	289.3	48.6	21.4
	Mean	307.7	254.0	56.2	22.3
Nadaun	Bharmoti	250.8	188.3	65.5	19.9
	Mewli	344.9	264.7	56.3	18.1
	Kohla	274.6	198.3	64.8	18.3
	Mean	290.1	217.1	62.2	18.8
Sujanpur	Bhalana	337.5	205.6	65.3	22.5
	Tikkar	313.6	282.2	54.6	18.3
	Chaunki	245.6	214.3	48.7	21.9
	Mean	298.9	234.0	56.2	20.9
District Mean		315.2	241.0	57.7	21.3
District Range		245.3-416.6	188.3-290.8	48.6-65.5	17.8-24.2
District- Una					
Amb	Amb	323.5	282.2	54.5	22.8
	Pramb	376.3	312.3	65.7	21.5
	Heera Nagar	313.6	250.8	42.3	24.0
	Mean	337.8	281.8	54.2	22.8
Bangana	Malangar	376.3	298.2	51.3	20.6
	Amrera	282.2	236.5	62.1	21.7

	Surda	345.6	245.8	58.3	22.4
	Mean	334.7	260.2	57.2	21.6
Gagret	Dolatpur	344.9	282.2	65.2	21.6
	Ghanari	257.9	212.3	56.2	23.8
	Deoli	282.2	178.5	62.3	19.4
	Mean	295.0	224.3	61.2	21.6
Haroli	Shatarpur	376.3	265.3	44.6	22.5
	Ghaluwal	282.2	240.8	40.8	17.3
	Bhadsali	312.8	255.6	45.2	20.9
	Mean	323.8	253.9	43.5	20.2
Una	Fatehpur	325.3	225.6	63.9	20.3
	Sasan	313.6	250.8	56.3	21.7
	Lal Singhi	257.6	190.3	47.9	22.4
	Mean	298.8	222.2	56.0	21.5
District Mean		318.0	248.4	54.4	21.5
District Range		257.6-376.3	178.5-312.3	40.8-65.7	17.3-24.0
District- Bilaspur					
Bilaspur Sadar	Manman	271.5	232.7	45.6	20.8
	Panjel Khurd	313.6	282.2	60.2	22.3
	Samari	282.2	245.2	40.2	21.2
	Mean	289.1	253.4	48.7	21.4
Ghumarwin	Bhadrog	281.5	245.6	41.3	23.9
	Jahri	313.6	278.5	57.2	20.2
	Loharwin	335.7	256.3	59.7	22.5
	Mean	310.3	260.1	52.7	22.2
Jhanduta	Galian	390.8	250.8	47.6	21.3
	Behran	345.2	282.2	45.8	19.5
	Amroha	312.4	245.1	58.3	23.4
	Mean	349.5	259.4	50.6	21.4
Shri Naina Devi Ji	Dabheta	396.5	273.4	65.3	23.6
	Kutahla	282.2	256.5	45.6	21.3
	Kulah	312.6	245.3	63.2	22.5
	Mean	330.4	258.4	58.0	22.5
District Mean		319.8	257.8	52.5	21.9
District Range		271.5-396.5	232.7-282.2	40.2-65.3	19.5-23.9
Overall Mean		317.4	248.0	55.2	21.5
Overall Range		245.3-416.6	178.5-312.3	40.2-65.7	17.3-24.2
Standard Error		2.58	2.08	1.04	0.38
CV		14.45	13.28	14.03	8.09
Standard Deviation		45.87	32.92	7.75	1.74

available phosphorous content, respectively under cultivated conditions and 21.4, 22.2, 21.4 and 22.5 kg ha^{-1} mean available phosphorous content, respectively under buffer conditions.

In overall study area, available phosphorous content varied from 40.2 to 65.3 kg ha^{-1} with a mean value of 55.2 kg ha^{-1} under vegetable cultivation, whereas in buffer conditions it varied from 17.3 to 24.2 kg ha^{-1} with a mean value of 21.5 kg ha^{-1}. Among districts, Hamirpur district recorded the highest mean available phosphorous content (57.7 kg ha^{-1}), whereas lowest mean available phosphorous content was observed in district Bilaspur (52.5 kg ha^{-1}). In overall, Pramb village in Amb block of Una district was found to have the highest available phosphorous content of 65.7 kg ha^{-1}, while Samari village in Bilaspur Sadar block of Bilaspur district recorded the lowest available phosphorous content of 40.2 kg ha^{-1} under cultivated conditions. The CV of 14.03 and 8.09 under cultivated and buffer conditions indicate that it varied spatially. Average available phosphorous content was found comparatively lower (21.5 kg ha^{-1}) under buffer conditions over cultivated conditions (55.2 kg ha^{-1}). The higher available phosphorous contents under cultivated conditions in comparison to buffer conditions might be due to frequent application of organic manure and fertilizers to obtain higher yields. All the soil samples of the studied area fall under high category of available phosphorous. Bajpai *et al.* (2006) and Reddy *et al.* (2006) also reported that use of fertilizers with manure increased the available phosphorous content of the soil. Tolanur and Badanur (2003) also found that organic matter like FYM and green manure along with inorganic fertilizers had the beneficial effect on increasing the phosphate availability. The results of the study areas are in agreement with findings of Sharma (2011), Chandel (2013), Shabnam (2018) and Suri (2018).

vi. Available potassium

An insight into the data in table 4.6 revealed that in Hamirpur district available potassium content of soil under vegetable cultivation varied from 198.4 to 432.2 kg ha^{-1} with a mean value of 334.6 kg ha^{-1} and under buffer conditions it ranged from 119.2 to 278.5 kg ha^{-1} with a mean value of 215.6 kg ha^{-1}. Gulela village of Bamson block recorded highest and Khagal village of Hamirpur block recorded lowest content of available potassium under vegetable cultivation. Under buffer conditions the highest available potassium content was observed in Gulela village of Bamson block while lowest was observed in Bhalana village of Sujanpur block. Among different blocks of Hamirpur district, highest mean available potassium content under cultivated conditions was recorded in Bijari block (416.2 kg ha^{-1})

and lowest mean available potassium content was recorded in Hamirpur block (255.1 kg ha^{-1}).

The available potassium of soils under vegetable cultivation in Una district varied from 147.2 to 546.1 kg ha^{-1} with a mean value of 342.5 kg ha^{-1}, whereas, in buffer conditions it ranged from 117.7 to 310.3 kg ha^{-1} with a mean value of 223.1 kg ha^{-1}. The highest available potassium content under cultivated conditions of Una district was observed in Ghaluwal village of Haroli block, while the lowest was recorded in Amb village of Amb block. Under buffer conditions the highest available potassium content was observed in Bhadsali village of Haroli block while lowest was observed in Amb village of Amb block. On comparing different blocks of Una district, it was observed that under both cultivated and buffer conditions, Haroli block recorded highest mean available potassium content (457.1 and 262.3 kg ha^{-1}, respectively), while lowest mean available potassium content was observed in Amb block (186.7 and 151.7 kg ha^{-1}, respectively).

In Bilaspur district, available potassium content of soil varied from 240.7 to 400.7 kg ha^{-1} with a mean value of 315.6 kg ha^{-1}, whereas, in buffer conditions it ranged between 189.7 to 315.7 kg ha^{-1} with a mean value of 236.4 kg ha^{-1}. The highest available potassium content under cultivated conditions were recorded in Bhadrog village of Ghumarwin block and lowest in Kulah village of Shri Naina Devi Ji block. Under buffer conditions the lowest available potassium content was observed in Behran village of Jhanduta block while highest was observed in Bhadrog village of Ghumarwin block. On comparing different blocks of Bilaspur district, it was observed that under cultivated and buffer conditions, Bilaspur Sadar block recorded highest available potassium content (360.4 and 274.5 kg ha^{-1}, respectively) followed by Ghumarwin block (348.9 and 255.9 kg ha^{-1}, respectively) and Jhanduta block (278.4 and 216.6 kg ha^{-1}, respectively) while lowest available potassium content was observed in Shri Naina Devi Ji block (274.6 and 198.6 kg ha^{-1}, respectively).

The available potassium content of soils in overall studied area under cultivated conditions varied from 147.2 to 546.1 kg ha^{-1} with a mean value of 332.2 kg ha^{-1}, whereas, in buffer conditions it ranged from 117.7 to 315.7 kg ha^{-1} with a mean value of 223.7 kg ha^{-1}. In overall, the highest available potassium content under cultivated conditions was observed in Ghaluwal village (546.1 kg ha^{-1}) of Haroli block of Una district, while the lowest available potassium was recorded in Amb village (147.2 kg ha^{-1}) of Amb block of Una district. Among districts, under cultivated conditions Una district recorded the highest mean available potassium (342.5 kg ha^{-1}), whereas lowest mean available potassium value was observed in

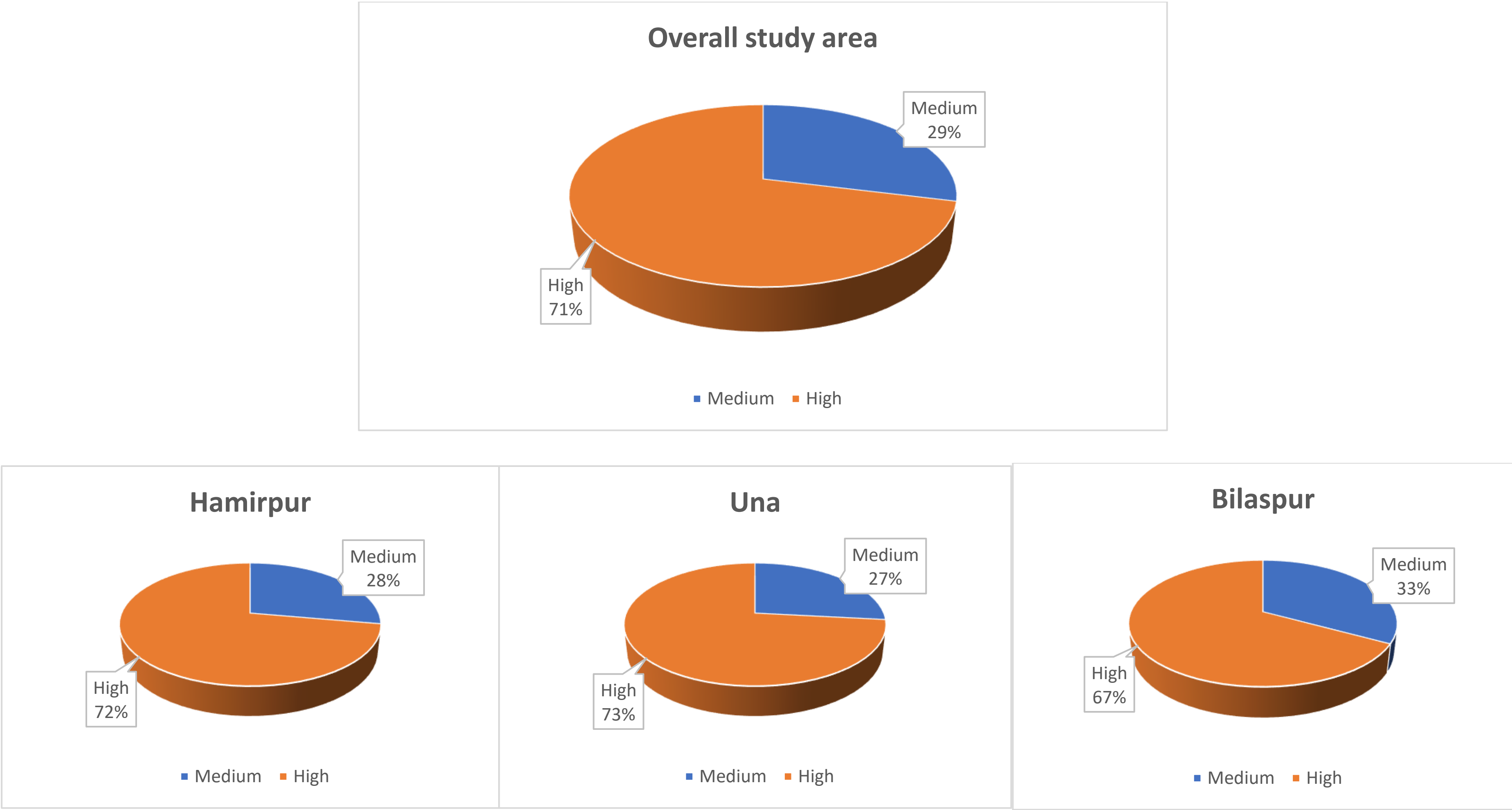


Figure 4.4 Percentage distribution of available potassium

district Bilaspur (315.6 kg ha^{-1}). The CV of 24.63 and 22.73 under cultivated and buffer conditions, respectively indicates that it varied spatially. Overall mean available potassium content was found lower (223.7 kg ha^{-1}) under buffer conditions as compared to cultivated conditions (332.2 kg ha^{-1}). The studied area had a medium to high potassium content and seventy one per cent soils samples of the studied area fall under high level of potassium and rest twenty nine fall in medium level as shown in figure 4, which could be attributed to the presence of potassium-rich minerals like illite and feldspars, as well as the release of labile potassium from organic residues and potassium fertilisers. These results are in conformity with the findings of Hassan *et al.* (2017) and Arshad (2020).

vii. Available sulphur

A persual of data presented in table 4.6 revealed that available sulphur in Hamirpur district under cultivated condition varied from 8.4 to 18.3 kg ha^{-1} with a mean value of 13.2 kg ha^{-1} and under buffer condition it ranged from 6.5 to 12.9 kg ha^{-1} with a mean value of 9.7 kg ha^{-1}. Bilkar Kahan village of Bijhari block recorded highest and Bhalana village of Sujanpur block observed lowest available sulphur content of soils under vegetable cultivation. The highest available sulphur content under buffer conditions was observed in Kakru village of Hamirpur block while lowest was observed in Bhalana village of Sujanpur block. On comparing different blocks of Hamirpur district it was observed that under cultivated conditions, Bijhari block recorded highest available sulphur content (15.5 kg ha^{-1}) while lowest available sulphur content was observed in Nadaun block (10.4 kg ha^{-1}).

In Una district, the available sulphur content of soils under vegetable cultivation varied from 8.6 to 14.6 kg ha^{-1} with a mean value of 11.8 kg ha^{-1}, whereas, in buffer conditions it ranged from 6.7 to 12.4 kg ha^{-1} with a mean value of 9.7 kg ha^{-1}. The highest available sulphur content under cultivated condition was observed in Amb village of Amb block, while the lowest was recorded in Deoli village of Gagret block. Under buffer condition, highest available sulphur content was observed in Bhadsali village of Haroli block while lowest was recorded in Deoli village of Gagret block. Among different blocks of Una district, highest mean available sulphur under cultivated condition was recorded in Haroli block (13.3 kg ha^{-1}) and lowest was recorded in Gagret block (9.8 kg ha^{-1}). Similar block wise trend of available sulphur was also observed under buffer conditions.

In Bilaspur district, available sulphur content of soils under cultivated conditions varied from 11.3 to 20.3 kg ha^{-1} with a mean value of 16.0 kg ha^{-1} whereas, under buffer

Table 4.6 Status of available potassium and sulphur (kg ha^{-1}) of soils under cultivated and buffer conditions

Block	Sites	Available potassium (kg ha^{-1})		Available sulphur (kg ha^{-1})	
		Cultivated	Buffer	Cultivated	Buffer
District- Hamirpur					
Bamson	Gulela	432.2	278.5	14.5	10.2
	Kangroo	390.5	256.3	10.2	7.5
	Halana	315.6	207.2	15.6	11.3
	Mean	379.4	247.3	13.4	9.7
Bhoranj	Jhandwin Changria	412.5	245.6	11.3	9.4
	Ghamarwin	245.5	194.5	15.3	10.3
	Bagwar	385.4	265.3	16.3	11.8
	Mean	347.8	235.1	14.3	10.5
Bijhari	Bilkar Kahan	427.7	270.7	18.3	12.1
	Patera	393.6	250.2	12.5	9.3
	Salan	427.2	278.3	15.6	11.2
	Mean	416.2	266.4	15.5	10.9
Hamirpur	Kakru	267.8	171.2	15.6	12.9
	Karahlar	299.1	200.3	12.3	10.2
	Khagal	198.4	144.6	16.3	10.8
	Mean	255.1	172.0	14.7	11.3
Nadaun	Bharmoti	317.3	211.5	9.3	7.1
	Mewli	346.8	256.3	11.3	8.4
	Kohla	212.3	186.9	10.6	6.9
	Mean	292.1	218.2	10.4	7.5
Sujanpur	Bhalana	265.3	119.2	8.4	6.5
	Tikkar	331.4	205.3	11.2	9.4
	Chaunki	354.2	139.6	12.3	9.8
	Mean	317.0	154.7	10.6	8.6
District Mean		334.6	215.6	13.2	9.7
District Range		198.4-432.2	119.2-278.5	8.4-18.3	6.5-12.9
District- Una					
Amb	Amb	147.2	117.7	14.6	11.3
	Pramb	162.5	124.8	9.5	7.5
	Heera Nagar	250.5	212.5	12.3	10.2
	Mean	186.7	151.7	12.1	9.7
Bangana	Malangar	356.4	221.6	9.9	7.6
	Amrera	474.2	274.6	13.3	11.2
	Surda	420.2	265.6	10.9	8.8

	Mean	416.9	253.9	11.4	9.2
Gagret	Dolatpur	358.9	218.3	11.3	9.7
	Ghanari	317.8	192.5	9.4	7.8
	Deoli	264.5	155.7	8.6	6.7
	Mean	313.7	188.8	9.8	8.1
Haroli	Shatarpur	395.4	189.2	12.3	10.3
	Ghaluwal	546.1	287.5	13.0	11.1
	Bhadsali	429.8	310.3	14.5	12.4
	Mean	457.1	262.3	13.3	11.3
Una	Fatehpur	310.8	264.8	12.3	10.4
	Sasan	387.6	278.6	12.5	9.8
	Lal Singhi	315.5	232.3	13.2	10.9
	Mean	338.0	258.6	12.7	10.4
District Mean		342.5	223.1	11.8	9.7
District Range		147.2-546.1	117.7-310.3	8.6-14.6	6.7-12.4
District- Bilaspur					
Bilaspur Sadar	Manman	360.5	265.3	11.3	9.8
	Panjel Khurd	375.7	290.6	13.6	11.2
	Samari	345.1	267.7	11.9	9.8
	Mean	360.4	274.5	12.3	10.3
Ghumarwin	Bhadrog	400.7	315.7	17.8	12.3
	Jahri	300.8	241.1	18.9	13.2
	Loharwin	345.3	210.8	14.5	10.7
	Mean	348.9	255.9	17.1	12.1
Jhanduta	Galian	310.5	252.8	18.6	12.7
	Behran	270.2	189.7	20.3	14.6
	Amroha	254.6	207.4	16.5	12.3
	Mean	278.4	216.6	18.5	13.2
Shri Naina Devi Ji	Dabheta	320.5	203.7	17.4	11.4
	Kutahla	262.5	193.6	16.5	12.8
	Kulah	240.7	198.6	14.8	11.2
	Mean	274.6	198.6	16.2	11.8
District Mean		315.6	236.4	16.0	11.8
District Range		240.7-400.7	189.7-315.7	11.3-20.3	9.8-14.6
Overall Mean		332.2	223.7	13.5	10.3
Overall Range		147.2-546.1	117.7-315.7	8.4-20.3	6.5-14.6
Standard Error		4.49	3.40	0.81	0.59
CV		24.63	22.73	22.11	18.47
Standard Deviation		81.81	50.83	2.98	1.91

conditions it ranged between 9.8 to 14.6 kg ha^{-1} with a mean value of 11.8 kg ha^{-1}. The highest available sulphur content under cultivated conditions was recorded in Behran village of Jhanduta block and lowest in Manman village of Bilaspur Sadar block. Bilaspur Sadar, Ghumarwin, Jhanduta and Shri Naina Devi Ji blocks recorded 12.3, 17.1, 18.5 and 16.2 kg ha^{-1} available sulphur content, respectively under cultivated conditions and 10.3, 12.1, 13.2 and 11.8 kg ha^{-1}, respectively under buffer conditions.

In overall study area, available sulphur content varied from 8.4 to 20.3 kg ha^{-1} with a mean value of 13.5 kg ha^{-1} under vegetable cultivation, whereas in buffer conditions it varied from 6.5 to 14.6 kg ha^{-1} with a mean value of 10.3 kg ha^{-1}. Among districts, Bilaspur district recorded the highest mean available sulphur (16.0 kg ha^{-1}), whereas lowest mean available sulphur was observed in district Una (11.8 kg ha^{-1}). In overall, Behran village in Jhanduta block of Bilaspur district was found to be have the highest available sulphur of 20.3 kg ha^{-1} while Bhalana village in Sujanpur block of Hamirpur district recorded the lowest content of available sulphur of 8.4 kg ha^{-1} under cultivated conditions. The CV of 22.11 and 18.47 under cultivated and buffer conditions, respectively indicates that it varied spatially. Average available sulphur content was found comparatively lower (10.3 kg ha^{-1}) under buffer conditions in contrast to cultivated conditions (13.5 kg ha^{-1}).

All the soils of the study area were found deficient in available sulphur content which could be due to high removal of sulphur by the cauliflower crop which leads to significant sulphur depletion in the soil. Further problem is aggravated as the farmers are not applying sulphur from any external source except little addition through FYM. Similar results were recorded by Kakar (2014) and Arshad (2020) in vegetable growing areas of Himachal Pradesh.

viii. Exchangeable calcium

The data presented in table 4.7 revealed that in Hamirpur district the exchangeable calcium content of the soils under cultivated conditions varied from 3.88 to 9.50 c mol (p^{+}) kg^{-1} with a mean value of 6.13 c mol (p^{+}) kg^{-1} and under buffer conditions it ranged from 3.45 to 7.45 c mol (p^{+}) kg^{-1} with a mean value of 5.26 c mol (p^{+}) kg^{-1}. Bilkar Kahan village of Bijhari block recorded highest and Kohla village of Nadaun block recorded lowest exchangeable calcium under both cultivated and buffer conditions. Among different blocks of Hamirpur district, highest mean exchangeable calcium content under cultivated and buffer conditions were recorded in Bijhari block [7.79 and 6.39 c mol (p+) kg^{-1}, respectively] and lowest exchangeable calcium was recorded in Sujanpur block [5.05 and 4.55 c mol (p+) kg^{-1}, respectively].

In Una district, the exchangeable calcium content of soils under vegetable cultivation varied from 4.68 to 9.25 c mol (p^+) kg^{-1} with a mean value of 6.67 c mol (p^+) kg^{-1} whereas, in buffer conditions it ranged from 4.12 to 8.90 c mol (p^+) kg^{-1} with a mean value of 5.74 c mol (p^+) kg^{-1}. The highest exchangeable calcium content under cultivated and buffer conditions were observed in Pramb village of Amb block, while the lowest was recorded in Malangar village of Bangana block. On comparing different blocks of Una district, it was observed that under both cultivated and buffer conditions, Amb block recorded highest mean exchangeable calcium content [7.67 and 7.03 c mol (p^+) kg^{-1}, respectively], while lowest mean exchangeable calcium content was observed in Bangana block [5.78 and 5.02 c mol (p^+) kg^{-1}, respectively].

In Bilaspur district, exchangeable calcium content varied from 3.20 to 8.18 c mol (p^+) kg^{-1} with a mean of value 5.79 c mol (p^+) kg^{-1}, whereas, in buffer conditions it ranged between 2.88 to 7.03 c mol (p^+) kg^{-1} with a mean value of 5.06 c mol (p^+) kg^{-1}. The highest values of exchangeable calcium under cultivated and buffer conditions were recorded in Galian village and lowest in Amroha village of Jhanduta block. Bilaspur Sadar, Ghumarwin, Jhanduta and Shri Naina Devi Ji blocks recorded 6.33, 5.18, 5.61 and 6.03 c mol (p^+) kg^{-1} mean exchangeable calcium content, respectively under cultivated conditions and 5.32, 4.62, 4.98 and 5.30 c mol (p^+) kg^{-1} mean exchangeable calcium content, respectively under buffer conditions.

The exchangeable calcium content of soils under cultivated conditions varied from 3.20 to 9.50 c mol (p^+) kg^{-1} with a mean value of 6.22 c mol (p^+) kg^{-1} whereas, under buffer conditions it ranged from 2.88 to 8.90 c mol (p^+) kg^{-1} with a mean value of 5.36 c mol (p^+) kg^{-1} in overall studied area. Among all the sites of study area under cultivated conditions, Amroha village in Jhanduta block of Bilaspur district was found to be have the lowest exchangeable calcium content of 3.20 c mol (p^+) kg^{-1} while, Bilkar Kahan village in Bijhari block of Hamirpur district had the highest exchangeable calcium content of 9.50 c mol (p^+) kg^{-1}. Among different districts, Una district recorded the highest mean exchangeable calcium content [6.67 c mol (p^+) kg^{-1}] under cultivated condition, whereas lowest mean exchangeable calcium content was observed in district Bilaspur [5.79 c mol (p^+) kg^{-1}]. Overall average exchangeable calcium content under cultivated conditions was found higher [6.22 c mol (p^+) kg^{-1}] as compared to buffer conditions [5.36 c mol (p^+) kg^{-1}]. The CV of 21.56 and 21.81 under cultivated and buffer conditions, respectively indicates that it varied spatially. Exchangeable calcium content of the study areas was high due to the regular addition of FYM which have higher adsorption capacity that might have adsorbed calcium which otherwise would have leached down. Similar results were also reported by Gupta and Tripathi (1989), Kaistha and Gupta (1993). Babu *et al*. (2007) also reported positive effect of FYM addition on exchangeable calcium in soil.

ix. Exchangeable magnesium

Critical analysis of data in the table 4.7 revealed that in Hamirpur district the exchangeable magnesium content of the soils under vegetable cultivation varied from 1.15 to 2.71 c mol (p^+) kg^{-1} with a mean value of 1.96 c mol (p^+) kg^{-1} while under buffer conditions it ranged from 1.04 to 2.23 c mol (p^+) kg^{-1} with a mean value of 1.63 c mol (p^+) kg^{-1}. Under both cultivated and buffer conditions Bilkar Kahan village of Bijhari block recorded highest and Kakru village of Hamirpur block recorded lowest exchangeable magnesium content. Among different blocks of Hamirpur district, highest mean exchangeable magnesium content under cultivated and buffer condition were recorded in Bijhari block [2.46 and 2.07 c mol (p+) kg^{-1}, respectively] and lowest exchangeable magnesium content was recorded in Hamirpur block [1.44 and 1.26 c mol (p+) kg^{-1}, respectively].

In Una district, the exchangeable magnesium content of soils under vegetable cultivation varied from 1.08 to 2.69 c mol (p^+) kg^{-1} with a mean value of 1.97 c mol (p^+) kg^{-1}, whereas, in buffer conditions it ranged from 0.75 to 2.47 c mol (p^+) kg^{-1} with a mean value of 1.64 c mol (p^+) kg^{-1}. The highest exchangeable magnesium content under cultivated conditions was observed in Ghaluwal village of Haroli block, while the lowest was recorded in Amrera village of Bangana block. On comparing different blocks of Una district, it was observed that under cultivated and buffer conditions, Una block recorded highest mean exchangeable magnesium content [2.40 and 2.05 c mol (p^+) kg^{-1}, respectively], while the lowest mean exchangeable magnesium content was observed in Amb block [1.38 and 1.14 c mol (p^+) kg^{-1}, respectively].

Exchangeable magnesium content of soil in Bilaspur district varied from 1.20 to 2.69 c mol (p^+) kg^{-1} with a mean value of 2.00 c mol (p^+) kg^{-1} whereas, in buffer conditions it ranged between 0.92 to 2.12 c mol (p^+) kg^{-1} with a mean value of 1.61 c mol (p^+) kg^{-1}. The highest exchangeable magnesium content under cultivated conditions was recorded in

Table 4.7 Status of exchangeable calcium and magnesium [cmol (p+) kg^{-1}] of soils under cultivated and buffer conditions

Block	Sites	Exchangeable calcium [cmol (p+) kg^{-1}]		Exchangeable magnesium [cmol (p+) kg^{-1}]	
		Cultivated	Buffer	Cultivated	Buffer
District- Hamirpur					
Bamson	Gulela	6.08	5.13	2.24	2.04
	Kangroo	7.54	6.41	2.38	1.87
	Halana	7.12	5.74	2.10	1.67
	Mean	6.91	5.76	2.24	1.86
Bhoranj	Jhandwin Changria	5.60	5.15	2.15	1.83
	Ghamarwin	6.03	5.46	2.00	1.75
	Bagwar	6.81	6.36	2.31	1.66
	Mean	6.15	5.66	2.16	1.75
Bijhari	Bilkar Kahan	9.50	7.45	2.71	2.23
	Patera	6.30	5.41	2.27	2.01
	Salan	7.56	6.32	2.39	1.98
	Mean	7.79	6.39	2.46	2.07
Hamirpur	Kakru	5.85	4.60	1.15	1.04
	Karahlar	5.10	4.41	1.42	1.24
	Khagal	4.35	4.75	1.75	1.50
	Mean	5.10	4.59	1.44	1.26
Nadaun	Bharmoti	5.73	3.98	2.13	1.55
	Mewli	7.68	6.34	2.28	1.79
	Kohla	3.88	3.45	1.21	1.07
	Mean	5.76	4.59	1.88	1.47
Sujanpur	Bhalana	4.15	3.74	1.24	1.09
	Tikkar	6.15	5.60	1.98	1.75
	Chaunki	4.85	4.32	1.60	1.29
	Mean	5.05	4.55	1.60	1.38
District Mean		6.13	5.26	1.96	1.63
District Range		3.88-9.50	3.45-7.45	1.15-2.71	1.04-2.23
District- Una					
Amb	Amb	5.54	5.06	1.21	1.02
	Pramb	9.25	8.90	1.60	1.19
	Heera Nagar	8.23	7.14	1.33	1.21
	Mean	7.67	7.03	1.38	1.14
Bangana	Malangar	4.68	4.12	2.13	1.74
	Amrera	6.75	5.93	1.08	0.75

	Surda	5.90	5.03	2.19	1.76
	Mean	5.78	5.02	1.80	1.42
Gagret	Dolatpur	5.53	4.17	1.64	1.45
	Ghanari	7.55	6.38	2.26	1.85
	Deoli	6.50	5.56	1.93	1.65
	Mean	6.53	5.37	1.94	1.65
Haroli	Shatarpur	7.35	6.28	2.36	2.10
	Ghaluwal	6.15	5.45	2.69	2.14
	Bhadsali	6.54	5.85	2.00	1.60
	Mean	6.68	5.86	2.35	1.95
Una	Fatehpur	5.50	4.25	2.41	2.12
	Sasan	8.73	7.23	2.15	1.56
	Lal Singhi	5.85	4.74	2.63	2.47
	Mean	6.69	5.41	2.40	2.05
District Mean		6.67	5.74	1.97	1.64
District Range		4.68-9.25	4.12-8.90	1.08-2.69	0.75-2.47
		District- Bilaspur			
Bilaspur Sadar	Manman	4.88	4.26	2.30	2.10
	Panjel Khurd	6.85	5.48	1.60	1.44
	Samari	7.25	6.23	1.89	1.52
	Mean	6.33	5.32	1.93	1.68
Ghumarwin	Bhadrog	4.60	4.21	2.69	1.87
	Jahri	4.85	4.23	1.87	1.54
	Loharwin	6.10	5.43	2.54	1.83
	Mean	5.18	4.62	2.37	1.75
Jhanduta	Galian	8.18	7.03	1.74	1.34
	Behran	5.45	5.04	2.56	2.12
	Amroha	3.20	2.88	1.20	0.92
	Mean	5.61	4.98	1.83	1.46
Shri Naina Devi Ji	Dabheta	6.00	5.12	1.80	1.41
	Kutahla	6.23	5.45	1.62	1.34
	Kulah	5.85	5.32	2.24	1.95
	Mean	6.03	5.30	1.89	1.57
District Mean		5.79	5.06	2.00	1.61
District Range		3.20-8.18	2.88-7.03	1.20-2.69	0.92-2.12
Overall Mean		6.22	5.36	1.98	1.63
Overall Range		3.20-9.50	2.88-8.90	1.08-2.71	0.75-2.47
Standard Error		0.55	0.50	0.33	0.31
CV		21.56	21.81	23.27	23.93
Standard Deviation		1.34	1.17	0.46	0.39

Bhadrog village of Ghumarwin block and lowest in Amroha village of Jhanduta block. Among different blocks of Bilaspur district, highest mean exchangeable magnesium content under cultivated and buffer condition were recorded in Ghumarwin block [2.37 and 1.75 c mol (p+) kg^{-1}, respectively] and lowest mean exchangeable magnesium content was recorded in Jhanduta block [1.83 and 1.46 c mol (p+) kg^{-1}, respectively].

The exchangeable magnesium content of soils in the overall studied area under vegetable cultivation varied from 1.08 to 2.71 c mol (p^+) kg^{-1} with a mean value of 1.98 cmol (p^+) kg^{-1}, while under buffer conditions it ranged from 0.75 to 2.47 c mol (p^+) kg^{-1} with a mean value of 1.63 c mol (p^+) kg^{-1}. Among all the sites of study area under cultivated conditions, Amrera village of Bangana block of Una district was found to be have the lowest exchangeable magnesium content of 1.08 c mol (p^+) kg^{-1} while, Bilkar Kahan village in Bijhari block of Hamirpur district recorded the highest exchangeable magnesium content of 2.71 c mol (p^+) kg^{-1}. Among different districts, Bilaspur district recorded the highest mean exchangeable magnesium content [2.00 c mol (p^+) kg^{-1}] under cultivated condition, whereas lowest mean exchangeable magnesium content was observed in district Hamirpur [1.96 c mol (p^+) kg^{-1}]. The CV of 23.27 and 23.93 under cultivated and buffer conditions, respectively indicates that it varied spatially.

All the soil samples of the studied area fall under high level of exchangeable magnesium. Overall average exchangeable magnesium content under cultivated conditions was found higher [1.98 c mol (p^+) kg^{-1}] as compared to buffer conditions [1.63 c mol (p^+) kg^{-1}]. The higher contents of exchangeable magnesium in cultivated soils are attributed to the higher organic matter content and neutral soil pH. The results trend is in testimony with the findings of Biswas *et al.* (2017), Chandel *et al*. (2017), Chauhan (2018) and Arshad (2020) in soils of Himachal Pradesh.

x. DTPA-extractable iron

The data on the DTPA-extractable iron content of the soil under different conditions and sites is presented in table 4.8. Perusal of the data revealed that DTPA-extractable iron in Hamirpur district under vegetable cultivation varied from 6.74 to 14.35 mg kg^{-1} with a mean value of 11.53 mg kg^{-1} and under buffer conditions it ranged from 5.45 to 12.32 mg kg^{-1} with a mean value of 9.33 mg kg^{-1}. Bhalana village of Sujanpur block recorded lowest and Bilkar Kahan village of Bijhari block recorded highest DTPA-extractable iron content of soils under cultivated and buffer conditions. Among different blocks of Hamirpur district, highest mean DTPA-extractable iron content under cultivated and buffer condition were recorded in Bijhari block (13.39 and 10.57 mg kg^{-1}, respectively), while lowest was recorded in Sujanpur block (8.94 and 7.20 mg kg^{-1}, respectively).

In Una district, the DTPA-extractable iron content of soils under vegetable cultivation varied from 5.56 to 11.58 mg kg^{-1} with a mean value of 8.21 mg kg^{-1}, whereas, in buffer conditions it ranged from 4.96 to 9.87 mg kg^{-1} with a mean value of 6.74 mg kg^{-1}. The highest DTPA-extractable iron content under cultivated conditions was observed in Ghanari village of Gagret block, while the lowest was recorded in Bhadsali village of Haroli block. On comparing different blocks of Una district, it was observed that under cultivated conditions, Gagret block recorded highest mean DTPA-extractable iron content (10.65 mg kg^{-1}) followed by Bangana block (8.91 mg kg^{-1}), Una (7.89 mg kg^{-1}) and Amb block (7.62 mg kg^{-1}) while lowest mean DTPA-extractable iron content was observed in Haroli block (5.98 mg kg^{-1}). Almost similar block wise trend of DTPA-extractable iron content of different blocks was observed for buffer condition.

In Bilaspur district, DTPA-extractable iron content under vegetable cultivation varied from 5.89 to 12.84 mg kg^{-1} with a mean value of 9.51 mg kg^{-1} whereas, under buffer conditions it ranged between 4.96 to 10.45 mg kg^{-1} with a mean value of 8.14 mg kg^{-1}. The highest DTPA-extractable iron content under cultivated and buffer conditions were recorded in Bhadrog village of Ghumarwin block and lowest in Manman village of Bilaspur Sadar block. Bilaspur Sadar, Ghumarwin, Jhanduta and Shri Naina Devi Ji blocks recorded 7.36, 11.33, 10.52 and 8.84 mg kg^{-1} mean DTPA-extractable iron content, respectively under cultivated conditions whereas, 6.48, 9.59, 8.72 and 7.78 mg kg^{-1}, respectively under buffer conditions.

The DTPA-extractable iron content of soils under vegetable cultivation varied from 5.56 to 14.35 mg kg^{-1} with a mean value of 9.89 mg kg^{-1}, whereas, in buffer conditions it ranged from 4.96 to 12.32 mg kg^{-1} with a mean value of 8.15 mg kg^{-1} in the overall studied area. In overall, the highest DTPA-extractable iron content under cultivated conditions was observed in Bilkar Kahan village (14.35 mg kg^{-1}) in Bijhari block of Hamirpur district, while the lowest DTPA-extractable iron was recorded in Badsali village (5.56 mg kg^{-1}) in Haroli block of Una district. Among districts, Hamirpur district recorded the highest mean DTPA-extractable iron content (11.53 mg kg^{-1}), whereas lowest mean DTPA-extractable iron content was observed in district Una (8.21 mg kg^{-1}). Overall mean soil DTPA-extractable iron content was found to be higher in cultivated conditions (9.89 mg kg^{-1}) as compared to

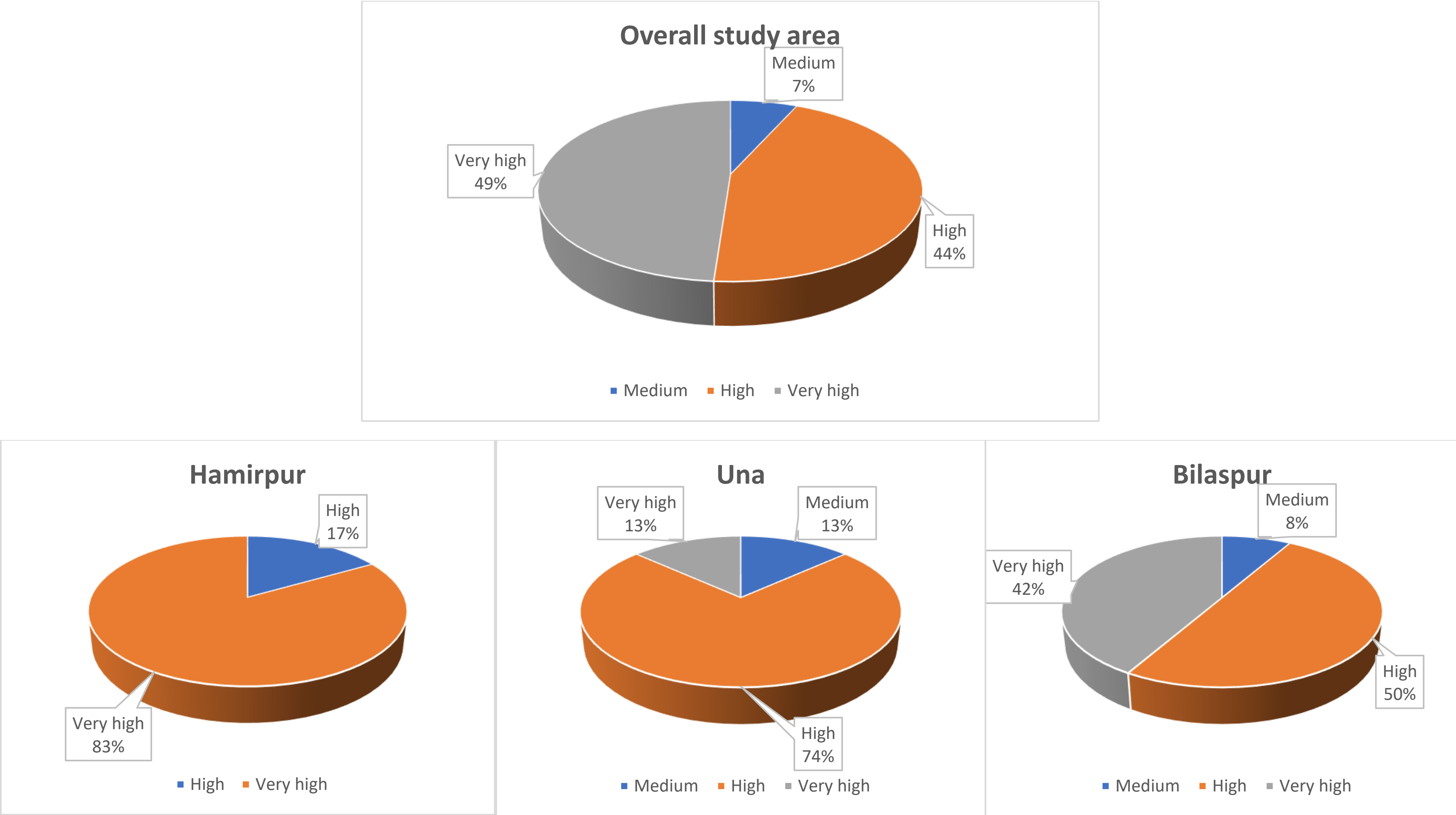


Figure 4.5 Percentage distribution of DTPA- extractable iron

buffer conditions (8.15 mg kg^{-1}). The CV of 23.77 under vegetable cultivation and 22.33 under buffer conditions indicates that it varied spatially. Forty nine per cent of soil samples of the study area fall under very high availability of iron, forty four per cent in high and rest seven per cent fall under medium availability of iron as shown in figure 5. Comparatively higher organic carbon content under cultivated conditions might have resulted in higher production of complexing agents which promoted better extractability of Fe in these soils. Sidhu and Sharma (2010) reported similar results in the soils of India's Indo-Gangetic plains.

xi. DTPA-extractable zinc

An insight into the data in table 4.8 revealed that DTPA-extractable zinc content in Hamirpur district under vegetable cultivation varied from 1.15 to 1.98 mg kg^{-1} with a mean value of 1.55 mg kg^{-1} whereas, under buffer conditions it ranged from 0.85 to 1.75 mg kg^{-1} with a mean value of 1.26 mg kg^{-1}. Gulela village of Bamson block recorded highest and Khagal village of Hamirpur block recorded lowest DTPA-extractable zinc content of soil under both cultivated and buffer conditions. Among different blocks of Hamirpur district, highest mean DTPA-extractable zinc content under cultivated conditions was recorded in Bijhari block (1.85 mg kg^{-1}) while lowest DTPA-extractable zinc content was noticed in Nadaun block (1.28 mg kg^{-1}).

In Una district, the DTPA-extractable zinc content of soils under vegetable cultivation varied from 1.08 to 1.86 mg kg^{-1} with a mean value of 1.30 mg kg^{-1}, whereas, in buffer conditions it ranged from 0.85 to 1.56 mg kg^{-1} with a mean value of 1.09 mg kg^{-1}. The highest DTPA-extractable zinc content under cultivated conditions was observed in Amb village of Amb block, while the lowest was recorded in Ghaluwal village of Haroli block. Amb, Bangana, Gagret, Haroli and Una recorded 1.54, 1.29, 1.25, 1.14 and 1.30 mg kg^{-1} mean DTPA-extractable zinc content, respectively under cultivated conditions and 1.28, 1.07, 1.06, 0.98 and 1.09 mg kg^{-1}, respectively under buffer conditions.

DTPA-extractable content zinc of soil in Bilaspur district varied from 0.92 to 1.58 mg kg^{-1} with a mean value of 1.24 mg kg^{-1}, whereas, in buffer conditions it ranged between 0.74 to 1.32 mg kg^{-1} with a mean value of 1.06 mg kg^{-1}. The highest DTPA-extractable zinc content under cultivated and buffer conditions were recorded in Behran village of Jhanduta block and lowest in Kutahla village of Shri Naina Devi Ji block. Among different blocks of Bilaspur district, highest mean DTPA-extractable zinc content under cultivated and buffer

Table 4.8 Status of DTPA-extractable iron and zinc (mg kg^{-1}) of soils under cultivated and buffer conditions

Block	Sites	DTPA-extractable iron (mg kg^{-1})		DTPA-extractable zinc (mg kg^{-1})	
		Cultivated	Buffer	Cultivated	Buffer
District- Hamirpur					
Bamson	Gulela	12.31	9.04	1.98	1.75
	Kangroo	14.23	11.14	1.65	1.40
	Halana	11.69	8.65	1.37	1.17
	Mean	12.74	9.61	1.67	1.44
Bhoranj	Jhandwin Changria	11.34	9.85	1.87	1.52
	Ghamarwin	10.32	8.64	1.32	1.04
	Bagwar	13.44	10.78	1.56	1.22
	Mean	11.70	9.76	1.58	1.26
Bijhari	Bilkar Kahan	14.35	12.32	1.97	1.52
	Patera	12.45	9.25	1.88	1.36
	Salan	13.37	10.14	1.68	1.42
	Mean	13.39	10.57	1.85	1.43
Hamirpur	Kakru	12.04	9.89	1.87	1.55
	Karahlar	11.56	8.56	1.35	1.18
	Khagal	10.45	9.08	1.15	0.85
	Mean	11.35	9.18	1.46	1.19
Nadaun	Bharmoti	10.82	9.64	1.26	0.91
	Mewli	12.56	10.42	1.38	1.17
	Kohla	9.85	8.87	1.21	1.02
	Mean	11.08	9.64	1.28	1.03
Sujanpur	Bhalana	6.74	5.45	1.4	1.28
	Tikkar	9.84	7.27	1.56	1.21
	Chaunki	10.24	8.87	1.45	1.17
	Mean	8.94	7.20	1.47	1.22
District mean		11.53	9.33	1.55	1.26
District Range		6.74-14.35	5.45-12.32	1.15-1.98	0.85-1.75
District- Una					
Amb	Amb	6.56	5.45	1.86	1.56
	Pramb	8.85	6.30	1.64	1.32
	Heera Nagar	7.45	6.14	1.12	0.95
	Mean	7.62	5.96	1.54	1.28
Bangana	Malangar	8.32	7.70	1.20	1.06
	Amrera	8.45	6.36	1.45	1.22

	Surda	9.96	7.24	1.23	0.92
	Mean	8.91	7.10	1.29	1.07
Gagret	Dolatpur	11.4	9.87	1.22	1.08
	Ghanari	11.58	9.12	1.13	0.85
	Deoli	8.96	7.82	1.40	1.24
	Mean	10.65	8.94	1.25	1.06
Haroli	Shatarpur	6.54	5.65	1.21	1.14
	Ghaluwal	5.84	5.12	1.08	0.87
	Bhadsali	5.56	4.96	1.12	0.92
	Mean	5.98	5.24	1.14	0.98
Una	Fatehpur	8.83	6.89	1.44	1.28
	Sasan	7.62	6.57	1.24	1.14
	Lal Singhi	7.22	5.92	1.23	0.85
	Mean	7.89	6.46	1.30	1.09
District mean		8.21	6.74	1.30	1.09
District Range		5.56-11.58	4.96-9.87	1.08-1.86	0.85-1.56
District- Bilaspur					
Bilaspur Sadar	Manman	5.89	4.96	1.30	1.15
	Panjel Khurd	8.62	7.84	1.16	1.04
	Samari	7.56	6.65	1.06	0.85
	Mean	7.36	6.48	1.17	1.01
Ghumarwin	Bhadrog	12.84	10.45	1.22	1.08
	Jahri	11.58	9.84	1.20	1.02
	Loharwin	9.56	8.47	1.10	0.87
	Mean	11.33	9.59	1.17	0.99
Jhanduta	Galian	10.23	8.74	1.42	1.27
	Behran	9.54	7.68	1.58	1.32
	Amroha	11.78	9.74	1.35	1.12
	Mean	10.52	8.72	1.45	1.24
Shri Naina Devi Ji	Dabheta	8.36	7.82	1.20	1.04
	Kutahla	7.62	7.21	0.92	0.74
	Kulah	10.54	8.32	1.35	1.21
	Mean	8.84	7.78	1.16	1.00
District Mean		9.51	8.14	1.24	1.06
District Range		5.89-12.84	4.96-10.45	0.92-1.58	0.74-1.32
Overall Mean		9.89	8.15	1.39	1.15
Overall Range		5.56-14.35	4.96-12.32	0.92-1.98	0.74-1.75
Standard Error		0.75	0.64	0.23	0.21
CV		23.77	22.33	19.49	19.96
Standard Deviation		2.35	1.82	0.27	0.23

condition were recorded in Jhanduta block (1.45 and 1.24 mg kg^{-1}, respectively) and lowest was recorded in Swarghar block (1.16 and 1.00 mg kg^{-1}, respectively).

In overall study area, the DTPA-extractable zinc content of soils under vegetable cultivation varied from 0.92 to 1.98 mg kg^{-1} with a mean value of 1.39 mg kg^{-1}, whereas, in buffer conditions it ranged from 0.74 to 1.75 mg kg^{-1} with a mean value of 1.15 mg kg^{-1}. In overall, the lowest DTPA-extractable zinc content under cultivated and buffer conditions was observed in Kuthala village (0.92 and 0.74 mg kg^{-1}, respectively) in Shri Naina Devi Ji block of Bilaspur district, while the highest DTPA-extractable zinc was recorded in Gulela village (1.98 and 1.75 mg kg^{-1}, respectively) in Bamson block of Hamirpur district. Among districts, Hamirpur district recorded the highest mean DTPA-extractable zinc content (1.55 mg kg^{-1}), whereas lowest was observed in district Bilaspur (1.24 mg kg^{-1}). Simliar district wise trend among of DTPA-extractable zinc was observed under buffer conditions. Overall mean soil DTPA-extractable zinc content was found to be higher in cultivated conditions (1.39 mg kg^{-1}) as compared to buffer conditions (1.15 mg kg^{-1}).

Zinc was found to be in medium availability in all the soils of the studied area. The CV of 19.49 and 19.96 under cultivated and buffer conditions indicates that it varied spatially. The high content of DTPA-extractable zinc in cultivated conditions may be due to higher organic carbon content and more favourable soil reaction. The results get strength from the findings of Biswas *et al.* (2017), Chandel *et al*. (2017), Chauhan (2018) and Arshad (2020) in soils of Himachal Pradesh.

xii. DTPA-extractable copper

Data pertaining to DTPA-extractable copper content of the soil under different conditions and sites is presented in table 4.9. Perusal of the data revealed that DTPA-extractable copper in Hamirpur district under cultivated conditions varied from 0.90 to 2.18 mg kg^{-1} with a mean value of 1.39 mg kg^{-1} and under buffer conditions it ranged from 0.72 to 1.94 mg kg^{-1} with a mean value of 1.20 mg kg^{-1}. Karahlar village of Hamirpur block recorded lowest and Ghamarwin village of Bhoranj block and Salan village of Bhijari block recorded highest DTPA-extractable copper content of soil under vegetable cultivation. Under buffer conditions lowest DTPA-extractable copper content was recorded in Chaunki village of Sujanpur block, whereas highest DTPA-extractable copper content was observed in Salan village of Bijhari block. Among different blocks of Hamirpur district, highest mean DTPA-extractable copper content under cultivated condition was recorded in Bhoranj block (1.93

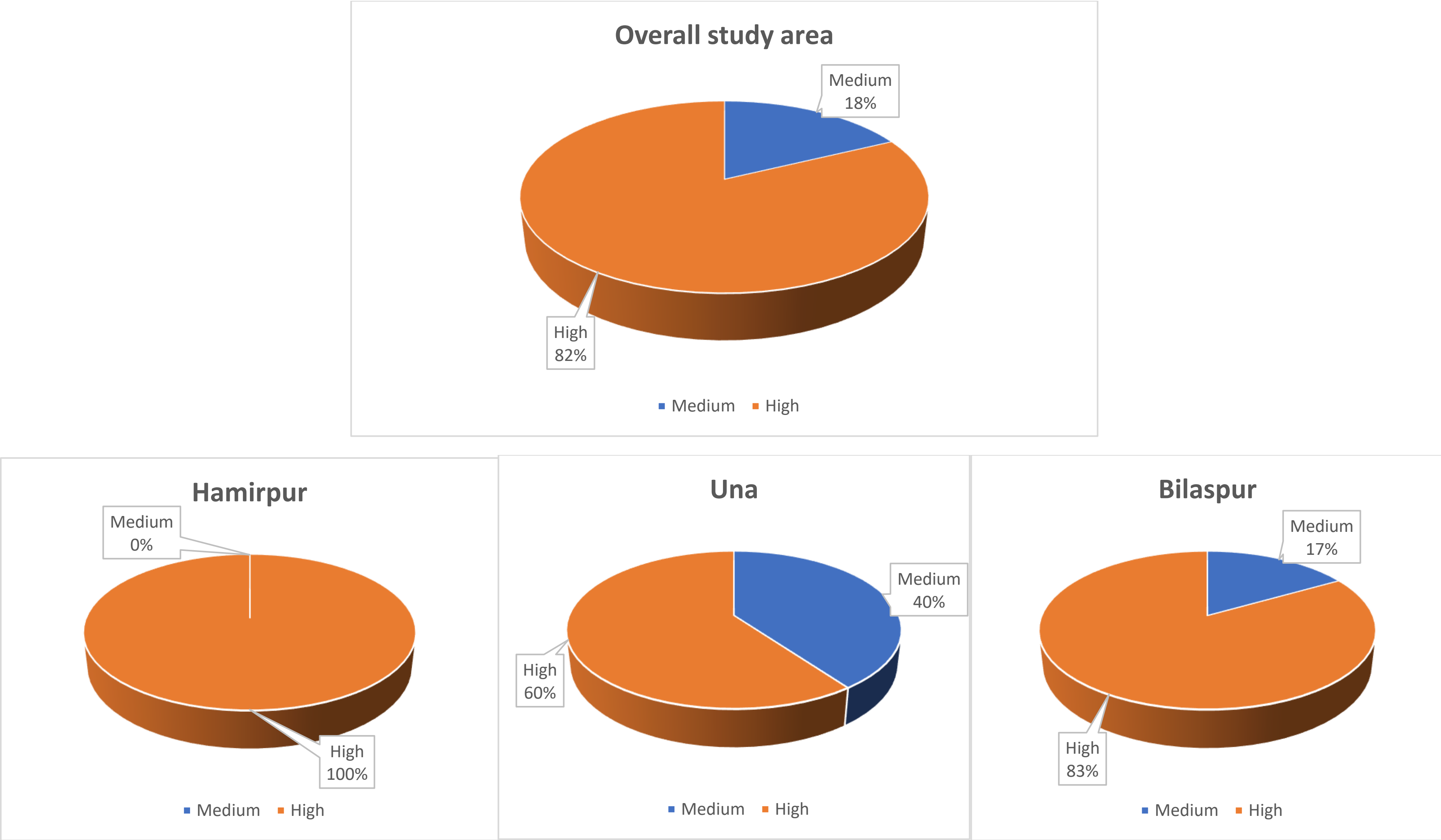


Figure 4.6 Percentage distribution of DTPA- extractable copper

mg kg^{-1}), while lowest DTPA-extractable copper content was recorded in Sujanpur block (1.04 mg kg^{-1}).

In Una district, the DTPA-extractable copper content of soils under vegetable cultivation varied from 0.63 to 1.31 mg kg^{-1} with a mean value of 0.84 mg kg^{-1}, whereas, in buffer conditions it ranged from 0.59 to 0.97 mg kg^{-1} with a mean value of 0.72 mg kg^{-1}. The highest DTPA-extractable copper content under cultivated conditions was observed in Fatehpur village of Una block, while the lowest was recorded in Malangar village of Bangana block. On comparing different blocks of Una district, it was observed that under both cultivated and buffer conditions, Haroli block recorded highest mean DTPA-extractable copper content (0.91 and 0.77 mg kg^{-1}, respectively), while lowest mean DTPA-extractable copper content was observed in Bangana block (0.70 and 0.64 mg kg^{-1}, respectively).

In Bilaspur district, soil DTPA-extractable copper content varied from 0.72 to 2.00 mg kg^{-1} with a mean value of 1.14 mg kg^{-1}, whereas, in buffer conditions it ranged between 0.61 to 1.67 mg kg^{-1} with a mean value of 0.96 mg kg^{-1}. The highest DTPA-extractable copper under cultivated conditions was recorded in Behran village of Jhanduta block and lowest was observed in Dabheta village of Shri Naina Devi Ji block. Under buffer conditions lowest DTPA-extractable copper content was recorded in Amroha village of Jhanduta block, whereas highest DTPA-extractable copper content was observed in Behran village of Jhanduta block. Bilaspur Sadar, Ghumarwin, Jhanduta and Shri Naina Devi Ji blocks recorded 1.18, 1.23, 1.20 and 0.97 mg kg^{-1} mean DTPA-extractable copper content, respectively under cultivated conditions whereas 0.91, 0.95, 0.99 and 0.99 mg kg^{-1} mean, respectively under buffer conditions.

In overall study area, the DTPA-extractable copper content of soils under vegetable cultivation varied from 0.63 to 2.18 mg kg^{-1} with a mean value of 1.14 mg kg^{-1}, whereas, in buffer conditions it ranged from 0.59 to 1.94 mg kg^{-1} with a mean value of 0.98 mg kg^{-1}. In overall, under cultivated conditions the lowest content of DTPA-extractable copper content was recorded in Malangar village (0.63 mg kg^{-1}) in Bangana block of Una district, while the highest DTPA-extractable copper content was observed in Ghamarwin village of Bhoranj block and Salan village of Bhijari block (2.18 mg kg^{-1}) of Hamirpur district. Among districts, Hamirpur district recorded the highest mean DTPA-extractable copper value (1.39 mg kg^{-1}), whereas lowest mean DTPA-extractable copper value was observed in district Una (0.84 mg kg^{-1}). The CV of 35.99 under vegetable cultivation and 35.84 under buffer conditions indicates that it varied spatially.

Table 4.9 Status of DTPA-extractable copper and manganese (mg kg^{-1}) of soils under cultivated and buffer conditions

Block	Sites	DTPA-extractable copper (mg kg^{-1})		DTPA-extractable manganese (mg kg^{-1})	
		Cultivated	Buffer	Cultivated	Buffer
District- Hamirpur					
Bamson	Gulela	1.17	1.04	3.54	3.12
	Kangroo	1.10	1.08	3.16	2.65
	Halana	1.82	1.67	2.91	2.45
	Mean	1.36	1.26	3.20	2.74
Bhoranj	Jhandwin Changria	1.73	1.51	3.25	2.87
	Ghamarwin	2.18	1.73	2.48	2.22
	Bagwar	1.87	1.62	2.20	1.97
	Mean	1.93	1.62	2.64	2.35
Bijhari	Bilkar Kahan	1.28	1.06	3.25	2.67
	Patera	1.51	1.37	2.98	2.36
	Salan	2.18	1.94	3.12	2.56
	Mean	1.66	1.46	3.12	2.53
Hamirpur	Kakru	0.99	0.86	1.94	1.68
	Karahlar	0.90	0.83	2.35	2.12
	Khagal	1.37	1.17	2.32	2.07
	Mean	1.09	0.95	2.20	1.96
Nadaun	Bharmoti	1.12	0.89	1.88	1.53
	Mewli	1.46	1.31	2.54	2.32
	Kohla	1.17	0.97	2.72	2.58
	Mean	1.25	1.06	2.38	2.14
Sujanpur	Bhalana	0.91	0.78	1.72	1.52
	Tikkar	1.21	1.13	2.54	2.23
	Chaunki	0.99	0.72	1.83	1.54
	Mean	1.04	0.88	2.03	1.76
District Mean		1.39	1.20	2.60	2.25
District Range		0.90-2.18	0.72-1.94	1.72-3.54	1.52-3.12
District- Una					
Amb	Amb	0.87	0.65	1.64	1.35
	Pramb	0.81	0.74	1.92	1.68
	Heera Nagar	0.95	0.84	2.08	1.74
	Mean	0.88	0.74	1.88	1.59
Bangana	Malangar	0.63	0.59	2.71	2.51
	Amrera	0.70	0.63	3.21	2.87

	Surda	0.77	0.70	2.91	2.63
	Mean	0.70	0.64	2.94	2.67
Gagret	Dolatpur	0.90	0.74	2.54	2.24
	Ghanari	0.83	0.72	1.65	1.36
	Deoli	0.71	0.67	1.74	1.45
	Mean	0.81	0.71	1.98	1.68
Haroli	Shatarpur	1.04	0.83	1.83	1.72
	Ghaluwal	0.81	0.72	1.90	1.63
	Bhadsali	0.88	0.75	1.78	1.55
	Mean	0.91	0.77	1.84	1.63
Una	Fatehpur	1.31	0.97	2.54	2.21
	Sasan	0.70	0.59	2.19	2.03
	Lal Singhi	0.68	0.61	1.91	1.72
	Mean	0.90	0.72	2.21	1.99
District Mean		0.84	0.72	2.17	1.91
District Range		0.63-1.31	0.59-0.97	1.64-3.21	1.35-2.87
District- Bilaspur					
Bilaspur Sadar	Manman	0.92	0.68	1.97	1.86
	Panjel Khurd	1.42	1.12	2.82	2.52
	Samari	1.19	0.93	2.31	2.17
	Mean	1.18	0.91	2.37	2.18
Ghumarwin	Bhadrog	1.13	0.87	3.22	3.09
	Jahri	1.60	1.13	2.56	2.24
	Loharwin	0.95	0.86	2.73	2.49
	Mean	1.23	0.95	2.84	2.61
Jhanduta	Galian	0.83	0.68	3.40	3.14
	Behran	2.00	1.67	2.89	2.76
	Amroha	0.77	0.61	2.89	2.63
	Mean	1.20	0.99	3.06	2.84
Shri Naina Devi Ji	Dabheta	0.72	0.70	2.54	2.21
	Kutahla	1.15	1.40	1.89	1.65
	Kulah	1.03	0.87	2.23	2.04
	Mean	0.97	0.99	2.22	1.97
District Mean		1.14	0.96	2.62	2.40
District Range		0.72-2.00	0.61-1.67	1.89-3.40	1.65-3.14
Overall Mean		1.14	0.98	2.46	2.18
Overall Range		0.63-2.18	0.59-1.94	1.64-3.54	1.35-3.14
Standard Error		0.38	0.36	0.35	0.34
CV		35.99	35.84	21.95	22.97
Standard Deviation		0.41	0.35	0.54	0.50

Eight two per cent soils of the studied area were found to be in high availability of copper and rest eighteen per cent fall in medium availability as shown in figure 6. Overall mean DTPA-extractable copper content was found to be higher in cultivated conditions (1.14 mg kg^{-1}) as compared to buffer conditions (0.98 mg kg^{-1}). Comparatively higher copper content in cultivated conditions may be explained on the basis of higher organic carbon because Cu forms Cu-humus complex of relatively high stability with humus that decreases its susceptibility to fixation or precipitation in the soil, Chandel *et al.* (2017) also observed application of *Blitox* (copper containing fungicide used for controlling diseases in vegetables) as one of the reasons for comparatively higher Cu content.

xiii. DTPA-extractable manganese

Critical analysis of the data presented in table 4.9 revealed that DTPA-extractable manganese content in Hamirpur district under vegetable cultivation varied from 1.72 to 3.54 mg kg^{-1} with a mean value of 2.60 mg kg^{-1} while in case of buffer conditions, it ranged from 1.52 to 3.12 mg kg^{-1} with a mean value of 2.25 mg kg^{-1}. Under cultivated and buffer conditions, Gulela village of Bamson block recorded highest and Bhalana village of Sujanpur block recorded lowest DTPA-extractable manganese content. Among different blocks of Hamirpur district, highest mean DTPA-extractable manganese under both cultivated and buffer conditions were recorded in Bamson block (3.20 and 2.74 mg kg^{-1}, respectively), while lowest DTPA-extractable manganese was observed in Sujanpur block (2.03 and 1.76 mg kg^{-1}, respectively).

In Una district, the DTPA-extractable manganese content of soils under vegetable cultivation varied from 1.64 to 3.21 mg kg^{-1} with a mean value of 2.17 mg kg^{-1}, whereas, in buffer conditions it ranged from 1.35 to 2.87 mg kg^{-1} with a mean value of 1.91 mg kg^{-1}. The highest DTPA-extractable manganese content under both cultivated and buffer conditions was observed in Amrera village of Bangana block, while the lowest was recorded in Amb village of Amb block. Amb, Bangana, Gagret, Haroli and Una blocks of Una district recorded 1.88, 2.94, 1.98, 1.84 and 2.21 mg kg^{-1} mean DTPA-extractable manganese content, respectively under cultivated conditions and 1.59, 2.67, 1.68, 1.63 and 1.99 mg kg^{-1}, respectively under buffer conditions.

In Bilaspur district, soil DTPA-extractable manganese content varied from 1.89 to 3.40 mg kg^{-1} with a mean value of 2.62 mg kg^{-1}, whereas, in buffer conditions it ranged between 1.65 to 3.14 mg kg^{-1} with a mean value of 2.40 mg kg^{-1}. The highest DTPA-extractable manganese content under cultivated and buffer conditions were recorded in Galian village of Jhanduta block and lowest in Kutahla village of Shri Naina Devi Ji block. Among different blocks of Bilaspur district, highest mean DTPA-extractable manganese content under cultivated and buffer conditions were recorded in Jhanduta block (3.06 and 2.84 mg kg^{-1}, respectively) and lowest was recorded in Shri Naina Devi Ji block (2.22 and 1.97 mg kg^{-1}, respectively).

The DTPA-extractable manganese content of soils in the overall studied area under vegetable cultivation varied from 1.64 to 3.54 mg kg^{-1} with a mean value of 2.46 mg kg^{-1}, whereas, in buffer conditions it ranged from 1.35 to 3.14 mg kg^{-1} with a mean value of 2.18 mg kg^{-1}. In overall, the lowest DTPA-extractable manganese value under cultivated conditions was observed in Amb village (1.64 mg kg^{-1}) of Amb block of Una district, while the highest DTPA-extractable manganese was recorded in Gulela village (3.54 mg kg^{-1}) of Bamson block of Hamirpur district. Among districts, Bilaspur district recorded the highest mean DTPA-extractable manganese value (2.62 mg kg^{-1}), whereas lowest mean DTPA-extractable manganese value was observed in district Una (2.17 mg kg^{-1}). Overall mean DTPA-extractable manganese content was found to be higher in cultivated conditions (2.46 mg kg^{-1}) as compared to buffer conditions (2.18 mg kg^{-1}). The CV of 21.95 and 22.97 under cultivated and buffer conditions indicate that it varied spatially. All the soils in the studied area fall under medium availability of manganese. Comparable values of DTPA-extractable manganese were also observed by Behera and Shukla (2014) in soils of Himachal Pradesh.

4.1.3 Microbiological properties

i. Microbial biomass carbon

A scrutiny of data presented in table 4.10 revealed that the microbial biomass carbon in Hamirpur district under cultivated conditions varied from 170.5 to 432.5 µg g^{-1} with a mean value of 284.1 µg g^{-1} whereas, under buffer conditions it ranged from 95.6 to 220.3 µg g^{-1} with a mean value of 148.6 µg g^{-1}. Bilkar Kahan village of Bijhari block recorded highest and Bhalana village of Sujanpur block recorded lowest microbial biomass carbon of soils under vegetable cultivation. Almost similar trend of microbial biomass carbon was observed under buffer conditions for different villages. Bamson, Bhoranj, Bijhari, Hamirpur, Nadaun and Sujanpur blocks recorded mean microbial biomass carbon values of 290.9, 292.0, 398.7, 247.3, 250.4 and 225.4 µg g^{-1}, respectively in cultivated conditions whereas, 168.9, 150.8, 204.4, 124.4, 119.8 and 123.3 µg g^{-1}, respectively under buffer conditions.

In Una district, the microbial biomass carbon of soils under vegetable cultivation varied from 165.2 to 332.3 µg g^{-1} with a mean value of 250.4 µg g^{-1}, whereas, in buffer conditions it ranged from 107.4 to 178.3 µg g^{-1} with a mean value of 142.0 µg g^{-1}. The highest microbial biomass carbon value under cultivated conditions was observed in Bhadsali village of Haroli block, while the lowest was recorded in Deoli village of Gagret block. Under buffer conditions highest microbial biomass carbon value was observed in Shatarpur village of Haroli block, while the lowest was recorded in Deoli village of Gagret block. Among different blocks of Una district, highest mean microbial biomass carbon under cultivated and buffer conditions was recorded in Haroli block (295.1 and 164.4 µg g^{-1}, respectively) and lowest was observed in Gagret block (202.5 and 118.9 µg g^{-1}, respectively).

In Bilaspur district, microbial biomass carbon varied from 245.2 to 415.8 µg g^{-1} with a mean value of 331.2 µg g^{-1}, whereas, in buffer conditions it ranged between 125.1 to 195.6 µg g^{-1} with a mean value of 157.3 µg g^{-1}. The highest microbial biomass carbon value under cultivated conditions was recorded in Dabheta village of Shri Naina Devi Ji block and lowest in Manman village of Bilaspur Sadar block. Under buffer conditions highest microbial biomass carbon value was observed in Loharwin village of Ghumarwin block, while the lowest was recorded in Manman village of Bilaspur Sadar block. Among different blocks of Bilaspur district, highest mean microbial biomass carbon under cultivated conditions was recorded in Shri Naina Devi Ji block (371.1 µg g^{-1}) and lowest mean microbial biomass carbon was recorded in Bilaspur Sadar block (275.7 µg g^{-1}).

Microbial biomass carbon contents varied from 165.2 to 432.5 µg g^{-1} with a mean value of 285.4 µg g^{-1} under cultivated conditions in the overall study area. Whereas, under buffer conditions microbial biomass carbon ranged from 95.6 to 220.3 µg g^{-1} with a mean value 148.7 µg g^{-1}. Among various sites selected for the study under vegetable production Bilkar Kahan village in Bijhari block of Hamirpur district (432.3 µg g^{-1}) recorded the highest microbial biomass carbon, whereas Deoli village in Gagret block of Una district recorded the lowest microbial biomass carbon (165.2 µg g^{-1}). Among districts, Bilaspur district recorded the highest mean microbial biomass carbon (331.2 µg g^{-1}), whereas lowest mean microbial biomass carbon was observed in district Una (250.4 µg g^{-1}). The CV of 21.55 under cultivated conditions and 18.71 under buffer conditions indicates that it varied spatially.

Mean microbial biomass carbon was found comparatively higher (285.4 µg g^{-1}) under cultivated conditions as compared to buffer conditions (148.7 µg g^{-1}). Comparatively higher

Table 4.10 Status of microbial biomass carbon and microbial biomass nitrogen ($\mu g\ g^{-1}$ soil) of soils under cultivated and buffer conditions

Block	Sites	MBC ($\mu g\ g^{-1}$ soil)		MBN ($\mu g\ g^{-1}$ soil)	
		Cultivated	Buffer	Cultivated	Buffer
District- Hamirpur					
Bamson	Gulela	320.1	170.3	30.2	14.2
	Kangroo	277.0	178.3	32.4	14.4
	Halana	275.5	158.2	28.5	13.8
	Mean	290.9	168.9	30.4	14.1
Bhoranj	Jhandwin Changria	256.3	127.7	25.7	11.2
	Ghamarwin	312.5	138.1	22.4	12.0
	Bagwar	307.2	186.5	24.5	14.6
	Mean	292.0	150.8	24.2	12.6
Bijhari	Bilkar Kahan	432.5	220.3	39.4	17.0
	Patera	356.2	192.6	37.2	16.2
	Salan	407.5	200.2	31.2	16.4
	Mean	398.7	204.4	35.9	16.5
Hamirpur	Kakru	265.3	143.4	22.1	12.7
	Karahlar	221.2	120.3	20.5	11.0
	Khagal	255.4	109.5	21.3	10.0
	Mean	247.3	124.4	21.3	11.2
Nadaun	Bharmoti	225.3	99.7	25.1	9.5
	Mewli	245.6	132.6	22.1	11.8
	Kohla	280.3	127.0	17.4	11.6
	Mean	250.4	119.8	21.5	11.0
Sujanpur	Bhalana	170.5	95.6	12.1	9.1
	Tikkar	245.3	142.5	23.5	12.6
	Chaunki	260.3	131.7	18.6	12.0
	Mean	225.4	123.3	18.1	11.2
District Mean		284.1	148.6	25.2	12.8
District Range		170.5-432.5	95.6-220.3	12.1-39.4	9.1-17.0
District- Una					
Amb	Amb	270.5	150.0	20.4	13.1
	Pramb	245.3	138.9	17.4	12.3
	Heera Nagar	227.2	131.4	20.5	12.0
	Mean	247.7	140.1	19.4	12.5
Bangana	Malangar	277.0	144.2	29.7	12.7
	Amrera	235.2	129.3	20.1	11.9
	Surda	265.4	155.2	17.6	13.0

	Mean	259.2	142.9	22.5	12.5
Gagret	Dolatpur	252.1	133.6	25.4	11.5
	Ghanari	190.3	115.7	21.5	10.5
	Deoli	165.2	107.4	15.3	10.1
	Mean	202.5	118.9	20.7	10.7
Haroli	Shatarpur	287.6	178.3	32.2	14.8
	Ghaluwal	265.4	143.2	29.4	13.1
	Bhadsali	332.3	171.8	25.1	14.5
	Mean	295.1	164.4	28.9	14.1
Una	Fatehpur	228.2	170.6	22.5	14.6
	Sasan	249.5	138.2	29.0	12.9
	Lal Singhi	265.4	122.5	19.8	10.9
	Mean	247.7	143.8	23.8	12.8
District Mean		250.4	142.0	23.1	12.5
District Range		165.2-332.3	107.4-178.3	15.3-32.2	10.1-14.8
District- Bilaspur					
Bilaspur Sadar	Manman	245.2	125.1	30.4	11.2
	Panjel Khurd	332.6	152.3	32.1	13.3
	Samari	249.3	131.4	24.6	11.5
	Mean	275.7	136.3	29.0	12.0
Ghumarwin	Bhadrog	298.4	161.8	35.7	13.5
	Jahri	387.2	151.4	27.6	13.2
	Loharwin	342.1	195.6	34.5	15.6
	Mean	342.6	169.6	32.6	14.1
Jhanduta	Galian	360.2	188.5	28.4	15.3
	Behran	359.0	143.2	25.1	14.8
	Amroha	287.2	163.9	27.9	13.8
	Mean	335.5	165.2	27.1	14.6
Shri Naina Devi Ji	Dabheta	415.8	165.4	29.1	14.1
	Kutahla	341.2	142.3	30.4	12.8
	Kulah	356.3	166.8	25.1	14.0
	Mean	371.1	158.2	28.2	13.6
District Mean		331.2	157.3	29.2	13.6
District Range		245.2-415.8	125.1-195.6	24.6-35.7	11.2-15.6
Overall Mean		285.4	148.7	25.6	12.9
Overall Range		165.2-432.5	95.6-220.3	12.1-39.4	9.1-17.0
Standard Error		3.64	2.28	1.19	0.51
CV		21.55	18.71	23.46	14.25
Standard Deviation		61.51	27.83	6.00	1.84

microbial biomass carbon under cultivated conditions might be attributed to higher organic carbon, which provided more substrate and favourable atmosphere for the microbes. The positive effect of soil organic matter on soil microbial biomass was more pronounced at most of the sites under cultivated conditions of vegetable production. The result was in trend line with the findings of Tripathi *et al.* (2006), Biswas *et al.* (2017), Chandel *et al.* (2017) and Shabnam (2018).

ii. Microbial biomass nitrogen

An insight into the data in table 4.10 revealed that microbial biomass nitrogen content in Hamirpur district under cultivated conditions varied from 12.1 to 39.4 µg g^{-1} with a mean value of 25.2 µg g^{-1} whereas, under buffer conditions it ranged from 9.1 to 17.0 µg g^{-1} with a mean value of 12.8 µg g^{-1}. Bilkar Kahan village of Bijhari block recorded highest and Bhalana village of Sujanpur block recorded lowest microbial biomass nitrogen of soil under vegetable cultivation. Almost similar trend of microbial biomass nitrogen content was observed under buffer conditions for different villages. On comparing different blocks of Hamirpur district it was observed that under cultivated conditions, Bijhari block recorded highest mean microbial biomass nitrogen content (35.9 µg g^{-1}) while lowest was observed in Sujanpur block (18.1 µg g^{-1}).

In Una district, the microbial biomass nitrogen content of soils under vegetable cultivation varied from 15.3 to 32.2 µg g^{-1} with a mean value of 23.1 µg g^{-1}, whereas, in buffer conditions it ranged from 10.1 to 14.8 µg g^{-1} with a mean value of 12.5 µg g^{-1}. The highest microbial biomass nitrogen content under cultivated and buffer conditions were observed in Shatarpur village of Haroli block, while the lowest was recorded in Deoli village of Gagret block. Among different blocks of Una district, highest mean microbial biomass nitrogen content under cultivated conditions was recorded in Haroli block (28.9 µg g^{-1}) and lowest was recorded in Amb block (19.4 µg g^{-1}).

In Bilaspur district, microbial biomass nitrogen content varied from 24.6 to 35.7 µg g^{-1} with a mean value of 29.2 µg g^{-1}, whereas, in buffer conditions it ranged between 11.2 to 15.6 µg g^{-1} with a mean value of 13.6 µg g^{-1}. The highest microbial biomass nitrogen content under cultivated conditions was recorded in Bhadrog village of Ghumarwin block and lowest in Samari village of Bilaspur Sadar block. Bilaspur Sadar, Ghumarwin, Jhanduta and Shri Naina Devi Ji blocks recorded 29.0, 32.6, 27.1 and 28.2 µg g^{-1} mean microbial biomass nitrogen content, respectively under cultivated conditions and 12.0, 14.1, 14.6 and 13.6 µg g^{-1}, respectively under buffer conditions.

In overall study area, microbial biomass nitrogen contents varied from 12.1 to 39.4 µg g^{-1} with a mean value of 25.6 µg g^{-1} under cultivated conditions in the study area. Whereas, under buffer conditions microbial biomass nitrogen content ranged from 9.1 to 17.0 µg g^{-1} with a mean value of 12.9 µg g^{-1}. Among various sites selected for the study under both cultivated and buffer conditions, Bilkar Kahan village of Bijhari block of Hamirpur district (39.4 and 17.0 µg g^{-1}, respectively) recorded the highest microbial biomass nitrogen content, whereas Bhalana village in Sujanpur block of Hamirpur district recorded the lowest microbial biomass nitrogen content (12.1 and 9.1 µg g^{-1}, respectively). Among districts, Bilaspur district recorded the highest mean microbial biomass nitrogen content (29.2 µg g^{-1}), whereas lowest was observed in district Una (23.1 µg g^{-1}). The CV of 23.46 under cultivated conditions and 14.25 under buffer conditions indicates that it varied spatially.

Mean microbial biomass nitrogen content of soil was found comparatively higher (25.6 µg g^{-1}) under cultivated conditions as compared to buffer conditions (12.9 µg g^{-1}). This could be due to high soil organic carbon content, increased root proliferation, and additional nitrogen supplied by FYM in addition to fertilizers. These results are in agreement with the findings of Mishra *et al.* (2008), Kumari *et al.* (2011) and Shabnam (2018).

iii. Soil respiration

Critical analysis of data presented in table 4.11 revealed that in Hamirpur district soil respiration under vegetable cultivation varied from 106.4 to 254.2 µg CO_2 g^{-1} soil per 24 hrs with a mean value of 172.2 µg CO_2 g^{-1} soil per 24 hrs whereas, under buffer conditions it ranged from 90.2 to 154.3 µg CO_2 g^{-1} soil per 24 hrs with a mean value of 113.6 µg CO_2 g^{-1} soil per 24 hrs. Bhalana village of Sujanpur block recorded lowest and Bilkar Kahan village of Bijhari block recorded highest soil respiration under both cultivated and buffer conditions. On comparing different blocks of Hamirpur district it was observed that under cultivated conditions, Bijhari block recorded highest mean soil respiration (221.0 µg CO_2 g^{-1} soil per 24 hrs), while lowest was observed in Sujanpur block (127.4 µg CO_2 g^{-1} soil per 24 hrs).

In Una district, the soil respiration under cultivated conditions varied from 95.3 to 175.2 µg CO_2 g^{-1} soil per 24 hrs with a mean value of 131.6 µg CO_2 g^{-1} soil per 24 hrs, whereas, in buffer conditions it ranged from 91.2 to 132.3 µg CO_2 g^{-1} soil per 24 hrs with a mean value of 108.0 µg CO_2 g^{-1} soil per 24 hrs. The highest soil respiration value under cultivated conditions was observed in Heera Nagar village of Amb block, while the lowest was recorded in Deoli village of Gagret block. Under buffer conditions highest soil respiration was recorded in Bhadsali village of Haroli block and lowest was observed in Deoli village of Gagret block. Among different blocks of Una district, highest mean soil respiration under cultivated conditions was recorded in Amb block (149.7 µg CO_2 g^{-1} soil per 24 hrs) and lowest soil respiration was recorded in Gagret block (109.4 µg CO_2 g^{-1} soil per 24 hrs).

Soil respiration in Bilaspur district varied from 119.5 to 242.5 µg CO_2 g^{-1} soil per 24 hrs with a mean value of 162.5 µg CO_2 g^{-1} soil per 24 hrs, whereas, in buffer conditions it ranged between 103.2 to 129.7 µg CO_2 g^{-1} soil per 24 hrs with a mean value of 116.6 µg CO_2 g^{-1} soil per 24 hrs. The highest soil respiration value under cultivated conditions was recorded in Loharwin village of Ghumarwin block and lowest in Panjel Khurd village of Bilaspur Sadar block. Among different blocks of Bilaspur district, highest mean soil respiration under cultivated conditions was recorded in Ghumarwin block (183.9 µg CO_2 g^{-1} soil per 24 hrs) and lowest mean soil respiration was recorded in Bilaspur Sadar block (130.9 µg CO_2 g^{-1} soil per 24 hrs), whereas in buffer conditions highest mean soil respiration was observed in Jhanduta block (123.2 µg CO_2 g^{-1} soil per 24 hrs) and lowest was recorded in Bilaspur Sadar block (104.8 µg CO_2 g^{-1} soil per 24 hrs).

Soil respiration varied from 95.3 to 254.2 µg CO_2 g^{-1} soil per 24 hrs with a mean value of 155.6 µg CO_2 g^{-1} soil per 24 hrs under vegetable cultivation, whereas in buffer conditions it varied from 90.2 to 154.3 µg CO_2 g^{-1} soil per 24 hrs with a mean value of 112.6 µg CO_2 g^{-1} soil per 24 hrs in the overall studied area. Among districts, Hamirpur district recorded the highest mean soil respiration (172.2 µg CO_2 g^{-1} soil per 24 hrs), whereas lowest mean soil respiration was observed in district Una (131.6 µg CO_2 g^{-1} soil per 24 hrs) under cultivated conditions. In overall, Bilkar Kahan village in Bijhari block of Hamirpur district was found to have the highest soil respiration of 254.2 µg CO_2 g^{-1} soil per 24 hrswhile Deoli village in Gagret block of Una district recorded the lowest soil respiration of 95.3 µg CO_2 g^{-1} soil per 24 hrs under cultivated conditions. The CV of 26.45 under cultivated conditions and 11.30 under buffer conditions indicates that it varied spatially. Average soil respiration was found comparatively lower (112.6 µg CO_2 g^{-1} soil per 24 hrs) under buffer conditions over to cultivated conditions (155.6 µg CO_2 g^{-1} soil per 24 hrs).

Table 4.11 Status of soil respiration (µg CO_2 g^{-1} soil per 24 hrs) under cultivated and buffer conditions

Block	**Sites**	**Soil Respiration (µg CO_2 g^{-1} soil per 24 hrs)**	
		Cultivated	**Buffer**
	District- Hamirpur		
Bamson	Gulela	242.3	121.3
	Kangroo	174.3	123.5
	Halana	187.2	118.4
	Mean	201.3	121.1
Bhoranj	Jhandwin Changria	198.6	103.1
	Ghamarwin	211.7	106.3
	Bagwar	234.2	125.2
	Mean	214.8	111.5
Bijhari	Bilkar Kahan	254.2	154.3
	Patera	187.5	130.2
	Salan	221.3	136.4
	Mean	221.0	140.3
Hamirpur	Kakru	142.3	112.3
	Karahlar	132.6	100.3
	Khagal	125.4	97.2
	Mean	133.4	103.3
Nadaun	Bharmoti	122.3	91.2
	Mewli	136.4	106.3
	Kohla	147.5	104.5
	Mean	135.4	100.7
Sujanpur	Bhalana	106.4	90.2
	Tikkar	154.3	116.8
	Chaunki	121.5	107.1
	Mean	127.4	104.7
District Mean		172.2	113.6
District Range		106.4-254.2	90.2-154.3
	District- Una		
Amb	Amb	117.5	110.3
	Pramb	156.3	108.3
	Heera Nagar	175.2	106.9
	Mean	149.7	108.5
Bangana	Malangar	140.6	116.7
	Amrera	165.2	106.7
	Surda	112.3	107.2
	Mean	139.4	110.2

Gagret	Dolatpur	122.5	107.1
	Ghanari	110.3	99.2
	Deoli	95.3	91.2
	Mean	109.4	99.2
Haroli	Shatarpur	127.6	104.1
	Ghaluwal	123.8	116.5
	Bhadsali	167.4	132.3
	Mean	139.6	117.6
Una	Fatehpur	121.3	103.4
	Sasan	112.4	108.2
	Lal Singhi	125.6	101.2
	Mean	119.8	104.3
District Mean		131.6	108.0
District Range		95.3-175.2	91.2-132.3
District- Bilaspur			
Bilaspur Sadar	Manman	129.5	103.2
	Panjel Khurd	119.5	105.1
	Samari	143.6	106.1
	Mean	130.9	104.8
Ghumarwin	Bhadrog	132.3	118.1
	Jahri	176.9	115.1
	Loharwin	242.5	129.7
	Mean	183.9	121.0
Jhanduta	Galian	212.3	126.3
	Behran	187.6	123.1
	Amroha	147.4	120.1
	Mean	182.4	123.2
Shri Naina Devi Ji	Dabheta	134.5	109.9
	Kutahla	176.5	112.3
	Kulah	147.2	120.4
	Mean	152.7	117.5
District Mean		162.5	116.6
District Range		119.5-242.5	103.2-129.7
Overall Mean		155.6	112.6
Overall Range		95.3-254.2	90.2-154.3
Standard Error		3.29	1.20
CV		26.45	11.30
Standard deviation		41.14	12.73

Variation in respiration rate due to variation in temperature and other climatological parameters was also observed by Rao and Patra (2009). Another reason for the increase in carbon dioxide evolution with increasing organic matter content of soil could be that the soils receiving higher organics application had increased levels of carbon in surface soil associated with increased levels of microbial biomass, microbial diversity and higher metabolic activity (Fraser *et al.* 1988). Soil CO_2 evolution was a function of root biomass also been well documented by Lalfakzuala *et al.* (2008). The result was in trend line with the findings of Shabnam (2018) and Kumar (2019).

4.2 Assessment of soil health

i. Principal component analysis

Principal component analysis (PCA) is a technique which is commonly used to reduce the dimensionality of huge data sets by converting a large collection of variables into a smaller set that retains the majority of the information from the larger data set. The primary goal of PCA is to reduce the dimension of data while minimising the loss of information (Armenise *et al*., 2013). Principal components (PCs) are new variables that are constructed as linear combinations or mixtures of the initial variables. These combinations are made in such a way that the new variables (principal components) are uncorrelated and first component contains the majority of the information from the original variables. So, PCA tries to put as much information as possible in the first component, then maximum remaining information in the second and so on. By organizing information into principal components in this manner, allows reducing dimensionality without losing much information, simply by eliminating the components with little information and considering the remaining components as the new variables. Results emerging from the principal components analysis of soil quality indicators under both cultivated and buffer conditions of sub montane and subtropical zone of Himachal Pradesh have been presented in table 4.12.

ii. Selection of minimum data set

Different soil quality indicators were chosen based on factor loading and contribution percentage values for soil health assessment. Soil properties with the highest factor loading were chosen for minimum data set (MDS) and the indicators that were not seen with the highest factor loadings, on the other hand were discarded from the MDS compilation process. The main components with the eigen values >1 are chosen. Only highly weighted factors (those with absolute values within 10% of the highest weight) were preserved for the MDS within each principal component. The strength of the relationships among variables was determined using a simple correlation matrix to reduce redundancy and rule out spurious groupings among the highly weighted variables within PCs. Principal components with a greater eigen value are thought to best represent the variation between the systems. As a result, only PCs with eigen values of 1 or more were considered for MDS creation (Wander and Bollero, 1999).

Table 4.12 Results from the Principal Components Analysis of soils under cultivated and buffer conditions

Principal components	**PC1**	**PC2**	**PC3**	**PC4**
Eigen value	7.882	2.516	1.562	0.994
Variability (%)	43.789	13.980	8.680	5.523
Cumulative (%)	43.789	57.769	66.449	71.972
weight	0.659	0.210	0.130	-
Potential MDS variables		Eigen vectors		
BD	-0.490	-0.186	**<u>0.755</u>**	-0.034
MWHC	0.568	0.182	-0.638	-0.124
pH	-0.172	**<u>0.892</u>**	0.098	-0.068
EC	0.106	0.713	0.028	-0.023
OC	**<u>0.948</u>**	0.171	0.120	-0.093
N	0.738	0.188	0.358	-0.068
P	0.763	0.132	0.285	-0.147
K	0.714	0.120	0.068	0.381
S	0.731	0.099	-0.125	-0.434
Ca	0.444	0.183	0.255	0.458
Mg	0.573	0.142	-0.220	0.595
Cu	0.465	-0.315	-0.343	0.044
Mn	0.584	-0.561	0.099	0.031
Fe	0.615	-0.585	-0.055	-0.008
Zn	0.572	-0.397	0.259	-0.041
MBC	**0.934**	0.161	0.074	-0.175
MBN	**0.909**	0.181	0.116	0.009
Soil respiration	0.848	-0.111	0.023	-0.069

Bold factor loadings are considered highly weighted; while bold underlined factor loadings were retained in MDS

In our study out of 18 variables in PCA, only three PCs had eigen value >1 and explained 66.449 per cent of the variance in the data for soil samples under cultivated and buffer conditions (Table 4.12). It can be conjectured from the data in table 4.12 that three highly weighted variables under PC1 included organic carbon, microbial biomass carbon and microbial biomass nitrogen within 10 per cent of the highest factor loading (0.948). Under

PC2 only pH, under PC3 only bulk density could get highest as well as within 10 per cent of highest factor loadings, other variables did not get enough loading to qualify for MDS formation. All the factor loadings under other PCs such as PC4 and so on were discarded for MDS preparation because their eigen values were less than 1. In PC1, organic carbon, microbial biomass carbon and microbial biomass nitrogen were the highly weighted attributes, which were significantly ($p < 0.01$) correlated with each other (r = 0. 950** and r = 0. 931**). So, among these only OC was included in the (Appendix-I) MDS.

After selecting the soil quality indicators for MDS, the linear scoring approach was used to score selected indicators in MDS into dimensionless values ranging from 0 to 1 (Liebig *et al.,* 2001). Once score is assigned to each indicator, weight is computed for them by using the PCA results. Each PC explained a certain amount of variation (%) in the total data set. This percentage, divided by the total percentage of variation explained by all PCs with eigen vectors greater than 1, provided the weighted factor for variables chosen under a given PC (Table 4.12). After scoring and weighting, the values were fed into weighted index and finally aggregate score indicating state of soil quality and the numerical value of soil quality (SQI) was obtained for each site under cultivated and buffer conditions of sub-montane and subtropical zone of Himachal Pradesh (Table 4.13 and Table 4.14).

iii. Scoring of minimum data set

After determining the MDS indicators, each MDS variable was scored on the basis of the performance of soil function, taking into account the differences in values across treatments. The score functions for each variable were transformed or standardised to a value between 0 (least favourable soil function) and 1 (most favourable soil function) (Andrews *et al*., 2002). Each indicator was categorised as "more is better" or "less is better" using the linear scoring approach. For 'more is better' indicators, each observation was divided by the highest observed value such that the highest observed value received a score of 1. For 'less is better' indicators, the lowest observed value (in the numerator) was divided by each observation (in the denominator) such that the lowest observed value receives a score of 1. For many indicators, such as pH observations were scored as 'higher is better' upto a threshold value then scored as 'lower is better' above the threshold.

Once score was assigned to each MDS variable, weight was calculated for them by using the PCA results. Each PC explained a certain amount of variation (%) in the total data set. This percentage of variation divided by the total per cent variation gave the weighted factor (Wi) for each selected indicator from the PCA (Singh *et al.*, 2013). This percentage, divided by the total percentage of variation explained by all PCs with eigen vectors greater than 1, provided the weighted factor for variables chosen under a given PC.

iv. Soil quality index and interpretation

After scoring and weighting, the values were fed into the additive model and finally the numerical value of soil quality index (SQI) was obtained for each site. By integrating score (Si) and weight (Wi) factor of each indicator, SQI was computed by using formula (SQI = Σ Si X Wi) for each site under cultivated and buffer conditions of sub-montane and subtropical zone of Himachal Pradesh (Table 4.13 and Table 4.14). Soil having a higher index score indicated better soil quality and better performance of soil quality indicators.

Data in table 4.15 revealed that in Hamirpur district, soil quality index under cultivated conditions varied from 0.583 to 0.982 with a mean value of 0.739 and under buffer conditions it ranged from 0.492 to 0.586 with a mean value of 0.537. Bilkar Kahan village of Bijhari block recorded highest and Bhalana village of Sujanpur block recorded lowest soil quality index under both cultivated and buffer conditions. Among different blocks of Hamirpur district, highest mean soil quality index under cultivated conditions was recorded in Bijhari block (0.924) and lowest was recorded in Nadaun block (0.650).

In Una district, the soil quality index under vegetable cultivation varied from 0.579 to 0.842 with a mean value of 0.701, whereas, in buffer conditions it ranged from 0.497 to 0.563 with a mean value of 0.529. The highest soil quality index under both cultivated and buffer conditions were observed in Shatarpurr village of Haroli block, while the lowest was recorded in Deoli village of Gagret block. On comparing different blocks of Una district, it was observed that under both cultivated and buffer conditions, Haroli block recorded highest mean soil quality index (0.794 and 0.549, respectively), while lowest was observed in Gagret block (0.633 and 0.511, respectively).

In Bilaspur district, soil quality index varied from 0.673 to 0.885 with a mean value of 0.783, whereas, in buffer conditions it ranged between 0.509 to 0.574 with a mean value of 0.544. The highest soil quality index under cultivated conditions was recorded in Galian village of Jhanduta block and lowest in Manman village of Bilaspur Sadar block. Under buffer condition the lowest soil quality index was observed in Samari village of Bilaspur Sadar block while highest was observed in Loharwin village of Ghumarwin block. On

Table 4.13 Score, weight and soil quality index (SQI) values of selected minimum data set (MDS) variables of soils under cultivated conditions

Site	BD		pH		OC		$SQI = \sum_{i=1}^{n} Wi\ X\ Si$
	Score (S)	Weight (W)	Score (S)	Weight (W)	Score (S)	Weight (W)	
Gulela	0.889	0.130	0.929	0.210	0.715	0.659	0.782
Kangroo	0.882	0.130	0.940	0.210	0.767	0.659	0.818
Halana	0.889	0.130	0.959	0.210	0.698	0.659	0.777
Jhandwin Changria	0.938	0.130	0.930	0.210	0.541	0.659	0.673
Ghamarwin	0.968	0.130	0.974	0.210	0.570	0.659	0.706
Bagwar	0.992	0.130	0.947	0.210	0.715	0.659	0.799
Bilkar Kahan	0.930	0.130	0.960	0.210	1.000	0.659	0.982
Patera	0.938	0.130	0.991	0.210	0.831	0.659	0.878
Salan	0.902	0.130	0.996	0.210	0.890	0.659	0.913
Kakru	0.938	0.130	0.993	0.210	0.593	0.659	0.721
Karahlar	0.909	0.130	0.953	0.210	0.506	0.659	0.652
Khagal	0.876	0.130	0.986	0.210	0.465	0.659	0.627
Bharmoti	0.909	0.130	0.983	0.210	0.436	0.659	0.612
Mewli	0.984	0.130	0.984	0.210	0.523	0.659	0.679
Kohla	0.916	0.130	0.987	0.210	0.506	0.659	0.660
Bhalana	0.889	0.130	0.986	0.210	0.395	0.659	0.583
Tikkar	0.952	0.130	0.996	0.210	0.610	0.659	0.735
Chaunki	0.945	0.130	0.985	0.210	0.564	0.659	0.701
Amb	0.902	0.130	0.947	0.210	0.651	0.659	0.745
Pramb	0.876	0.130	0.970	0.210	0.523	0.659	0.662
Heera Nagar	0.839	0.130	0.921	0.210	0.494	0.659	0.628

Malangar	0.923	0.130	0.987	0.210	0.610	0.659	0.730
Amrera	0.851	0.130	0.979	0.210	0.564	0.659	0.688
Surda	0.930	0.130	0.983	0.210	0.634	0.659	0.745
Dolatpur	0.960	0.130	0.966	0.210	0.605	0.659	0.726
Ghanari	0.916	0.130	0.963	0.210	0.413	0.659	0.593
Deoli	0.851	0.130	0.971	0.210	0.401	0.659	0.579
Shatarpur	0.984	0.130	0.940	0.210	0.785	0.659	0.842
Ghaluwal	0.938	0.130	0.916	0.210	0.669	0.659	0.755
Bhadsali	1.000	0.130	0.921	0.210	0.698	0.659	0.783
Fatehpur	0.909	0.130	0.966	0.210	0.610	0.659	0.723
Sasan	0.923	0.130	0.980	0.210	0.541	0.659	0.682
Lal Singhi	0.896	0.130	0.975	0.210	0.477	0.659	0.635
Manman	0.909	0.130	0.946	0.210	0.541	0.659	0.673
Panjel Khurd	0.889	0.130	0.970	0.210	0.640	0.659	0.741
Samari	0.851	0.130	0.938	0.210	0.570	0.659	0.683
Bhadrog	0.945	0.130	0.996	0.210	0.715	0.659	0.803
Jahri	0.923	0.130	0.983	0.210	0.651	0.659	0.756
Loharwin	0.968	0.130	0.967	0.210	0.843	0.659	0.884
Galian	0.952	0.130	0.977	0.210	0.843	0.659	0.885
Behran	0.930	0.130	0.956	0.210	0.791	0.659	0.843
Amroha	0.889	0.130	0.997	0.210	0.657	0.659	0.758
Dabheta	0.909	0.130	0.970	0.210	0.738	0.659	0.808
Kutahla	0.960	0.130	0.935	0.210	0.669	0.659	0.762
Kulah	0.923	0.130	0.960	0.210	0.727	0.659	0.801

Higher index scores meant better soil quality or greater performance of soil functions

Table 4.14 Score, weight and soil quality index (SQI) values of selected minimum data set (MDS) variables of soils under buffer conditions

Site	BD		pH		OC		$SQI = \sum_{i=1}^{n} Wi \ X \ Si$
	Score (S)	Weight (W)	Score (S)	Weight (W)	Score (S)	Weight (W)	
Gulela	0.882	0.130	0.926	0.210	0.355	0.659	0.543
Kangroo	0.851	0.130	0.936	0.210	0.360	0.659	0.545
Halana	0.909	0.130	0.951	0.210	0.337	0.659	0.540
Jhandwin Changria	0.938	0.130	0.924	0.210	0.302	0.659	0.515
Ghamarwin	0.960	0.130	0.957	0.210	0.314	0.659	0.533
Bagwar	0.976	0.130	0.940	0.210	0.366	0.659	0.566
Bilkar Kahan	0.909	0.130	0.951	0.210	0.407	0.659	0.586
Patera	0.916	0.130	0.996	0.210	0.384	0.659	0.581
Salan	0.882	0.130	0.993	0.210	0.390	0.659	0.580
Kakru	0.896	0.130	0.996	0.210	0.326	0.659	0.540
Karahlar	0.909	0.130	0.960	0.210	0.291	0.659	0.511
Khagal	0.857	0.130	0.983	0.210	0.273	0.659	0.498
Bharmoti	0.876	0.130	0.989	0.210	0.267	0.659	0.498
Mewli	0.968	0.130	0.977	0.210	0.308	0.659	0.534
Kohla	0.902	0.130	0.981	0.210	0.302	0.659	0.523
Bhalana	0.851	0.130	0.996	0.210	0.262	0.659	0.492
Tikkar	0.938	0.130	0.986	0.210	0.326	0.659	0.543
Chaunki	0.916	0.130	0.994	0.210	0.308	0.659	0.531
Amb	0.870	0.130	0.950	0.210	0.331	0.659	0.531
Pramb	0.870	0.130	0.975	0.210	0.314	0.659	0.525
Heera Nagar	0.822	0.130	0.928	0.210	0.308	0.659	0.505

Malangar	0.896	0.130	0.981	0.210	0.326	0.659	0.537
Amrera	0.822	0.130	0.971	0.210	0.308	0.659	0.514
Surda	0.889	0.130	0.986	0.210	0.331	0.659	0.541
Dolatpur	0.916	0.130	0.972	0.210	0.308	0.659	0.526
Ghanari	0.896	0.130	0.970	0.210	0.285	0.659	0.508
Deoli	0.839	0.130	0.974	0.210	0.279	0.659	0.497
Shatarpur	0.945	0.130	0.949	0.210	0.366	0.659	0.563
Ghaluwal	0.923	0.130	0.922	0.210	0.326	0.659	0.528
Bhadsali	0.952	0.130	0.927	0.210	0.360	0.659	0.556
Fatehpur	0.889	0.130	0.971	0.210	0.360	0.659	0.557
Sasan	0.916	0.130	0.989	0.210	0.314	0.659	0.534
Lal Singhi	0.882	0.130	0.985	0.210	0.297	0.659	0.517
Manman	0.902	0.130	0.949	0.210	0.302	0.659	0.516
Panjel Khurd	0.857	0.130	0.980	0.210	0.331	0.659	0.536
Samari	0.828	0.130	0.945	0.210	0.308	0.659	0.509
Bhadrog	0.896	0.130	0.983	0.210	0.337	0.659	0.545
Jahri	0.882	0.130	0.992	0.210	0.326	0.659	0.537
Loharwin	0.930	0.130	0.971	0.210	0.378	0.659	0.574
Galian	0.916	0.130	0.964	0.210	0.372	0.659	0.567
Behran	0.896	0.130	0.962	0.210	0.360	0.659	0.556
Amroha	0.876	0.130	0.987	0.210	0.343	0.659	0.547
Dabheta	0.896	0.130	0.980	0.210	0.349	0.659	0.552
Kutahla	0.923	0.130	0.951	0.210	0.326	0.659	0.534
Kulah	0.902	0.130	0.970	0.210	0.349	0.659	0.551

Higher index scores meant better soil quality or greater performance of soil functions comparing different blocks of Bilaspur district, it was observed that under cultivated and buffer conditions, Jhanduta block recorded highest mean soil quality index (0.828 and 0.557, respectively) while lowest was observed in Bilaspur Sadar block (0.699 and 0.520, respectively).

In overall study area, the soil quality index under vegetable cultivation varied from 0.579 to 0.982 with a mean value of 0.738 whereas, in buffer conditions it ranged from 0.492 to 0.586 with a mean value of 0.536. In overall, the highest soil quality index under cultivated conditions was observed in Bilkar Kahan village (0.982) in Bijhari block of Hamirpur district, while the lowest was recorded in Deoli village (0.579) in Gagret block of Una district. Under buffer conditions Bhalana village of Sujanpur block (0.492) recorded the lowest soil quality index and highest soil quality index was observed in Bilkar Kahan of Bijhari block (0.586). Among districts, under cultivated conditions Bilaspur district recorded the highest mean soil quality index (0.783), whereas lowest mean soil quality index was observed in district Una (0.701), same trend of mean soil quality index was observed under buffer conditions as shown in figure 8. Overall mean soil quality index was found lower (0.536) under buffer conditions as compared to cultivated conditions (0.738). As shown in the figure 7, most of the soils of the studied area (93 %) fall under very high soil quality grade according to the classification criteria given by Li *et al*. (2018).

4.3 Yield

Data pertaining to yield of cauliflower crop is given in the table 4.16. An insight into the data revealed that yield of cauliflower crop in Hamirpur district varied from 157.5 to 228.5 q ha^{-1} with a mean value of 186.1 q ha^{-1}. Among villages of Hamirpur district under different blocks, Bilkar Kahan village of Bijhari block recorded the highest yield (228.5 q ha^{-1}), whereas lowest yield was observed in village Bharmoti of Nadaun block (157.5 q ha^{-1}). Among all blocks of Hamirpur district, Bijhari block (216.5 q ha^{-1}) recorded the highest and Hamirpur block (167.6 q ha^{-1}) recorded the lowest mean yield.

In Una district yield of cauliflower crop ranged from 155.8 to 205.7 q ha^{-1} with a mean value of 177.1 q ha^{-1}. Among villages, lowest yield of 155.8 q ha^{-1} was recorded in village Heera Nagar of Amb block, whereas Shatarpur village of Haroli block recorded the highest yield of 205.7 q ha^{-1}. Haroli block (196.0 q ha^{-1}) recorded the highest and Gagret block (165.6 q ha^{-1}) recorded the lowest mean yield.

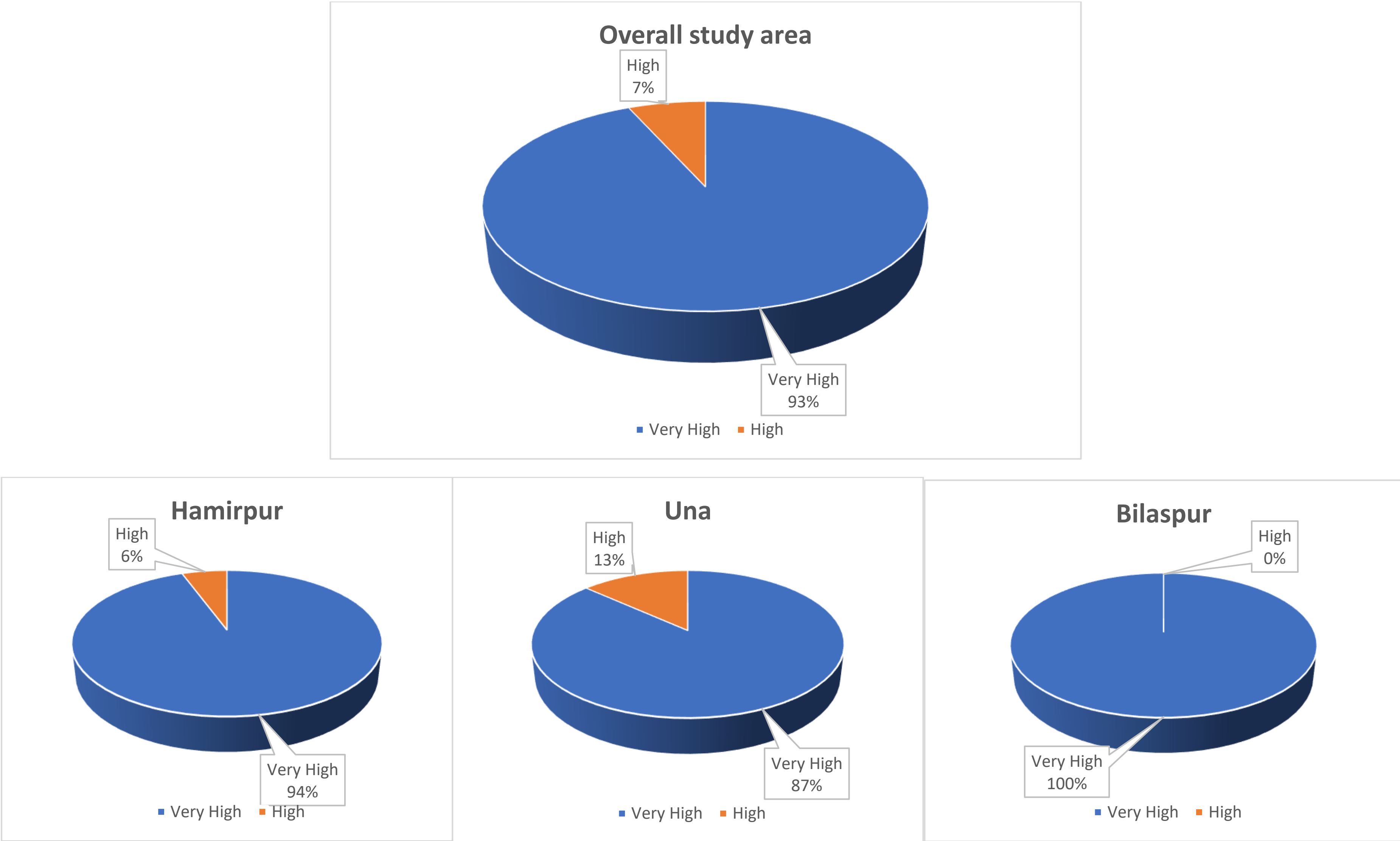


Figure 4.7 Interpretation of SQI

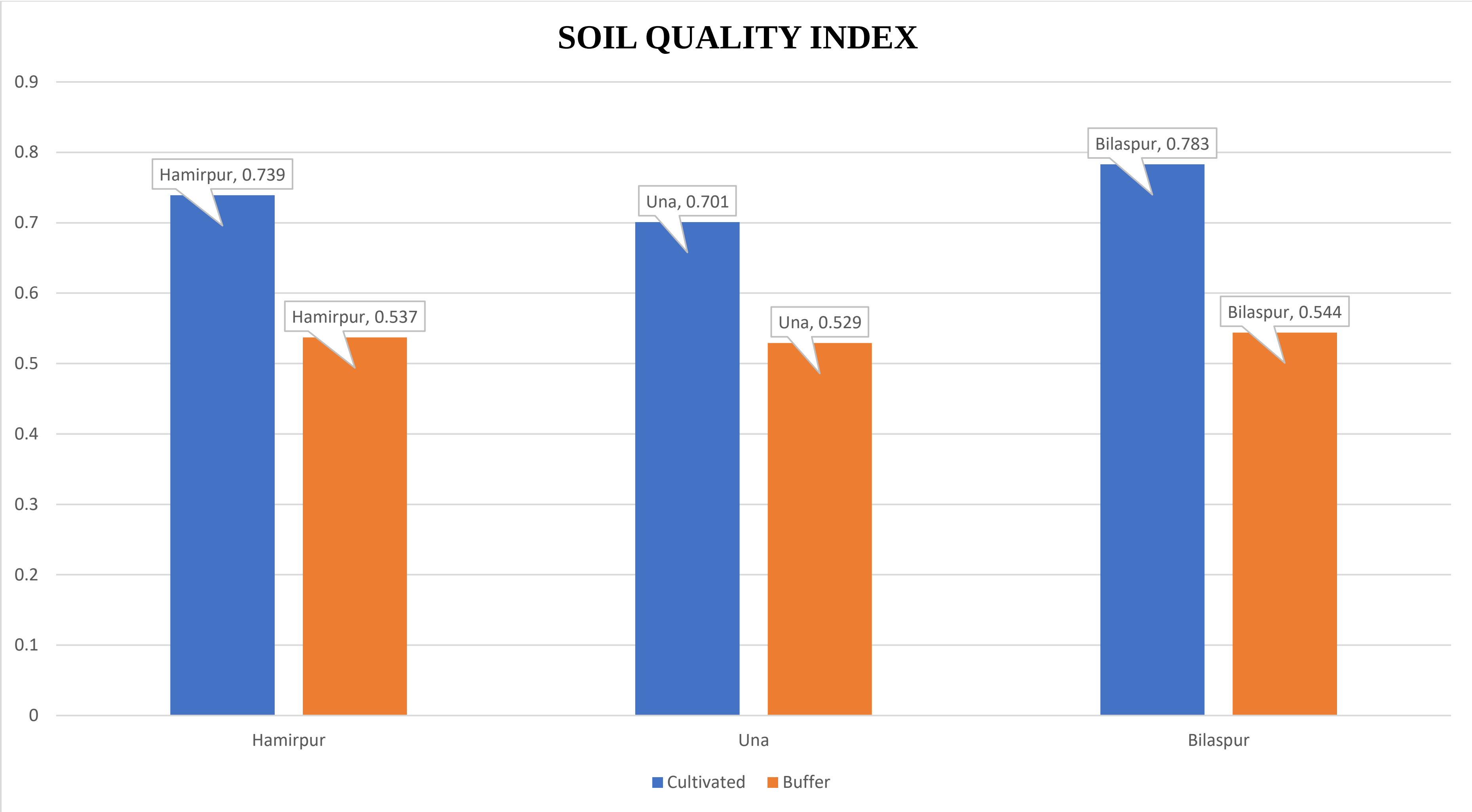


Figure 4.8 Soil quality index of Hamirpur, Una and Bilaspur district

comparing different blocks of Bilaspur district, it was observed that under cultivated and buffer conditions, Jhanduta block recorded highest mean soil quality index (0.828 and 0.557, respectively) while lowest was observed in Bilaspur Sadar block (0.699 and 0.520, respectively).

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Table 4.15 Soil quality index of soils under cultivated and buffer conditions

Block	Sites	Soil Quality Index (SQI)	
		Cultivated	Buffer
District- Hamirpur			
Bamson	Gulela	0.782	0.543
	Kangroo	0.818	0.545
	Halana	0.777	0.540
	Mean	0.792	0.543
Bhoranj	Jhandwin Changria	0.673	0.515
	Ghamarwin	0.706	0.533
	Bagwar	0.799	0.566
	Mean	0.726	0.538
Bijhari	Bilkar Kahan	0.982	0.586
	Patera	0.878	0.581
	Salan	0.913	0.580
	Mean	0.924	0.582
Hamirpur	Kakru	0.721	0.540
	Karahlar	0.652	0.511
	Khagal	0.627	0.498
	Mean	0.667	0.516
Nadaun	Bharmoti	0.612	0.498
	Mewli	0.679	0.534
	Kohla	0.660	0.523
	Mean	0.650	0.518
Sujanpur	Bhalana	0.583	0.492
	Tikkar	0.735	0.543
	Chaunki	0.701	0.531
	Mean	0.673	0.522
District Mean		0.739	0.537
District Range		0.583-0.982	0.492-0.586
District- Una			
Amb	Amb	0.745	0.531
	Pramb	0.662	0.525
	Heera Nagar	0.628	0.505
	Mean	0.679	0.520
Bangana	Malangar	0.730	0.537
	Amrera	0.688	0.514
	Surda	0.745	0.541
	Mean	0.721	0.531
Gagret	Dolatpur	0.726	0.526

	Ghanari	0.593	0.508
	Deoli	0.579	0.497
	Mean	0.633	0.511
Haroli	Shatarpur	0.842	0.563
	Ghaluwal	0.755	0.528
	Bhadsali	0.783	0.556
	Mean	0.794	0.549
Una	Fatehpur	0.723	0.557
	Sasan	0.682	0.534
	Lal Singhi	0.635	0.517
	Mean	0.680	0.536
District Mean		0.701	0.529
District Range		0.579-0.842	0.497-0.563
District- Bilaspur			
Bilaspur Sadar	Manman	0.673	0.516
	Panjel Khurd	0.741	0.536
	Samari	0.683	0.509
	Mean	0.699	0.520
Ghumarwin	Bhadrog	0.803	0.545
	Jahri	0.756	0.537
	Loharwin	0.884	0.574
	Mean	0.814	0.552
Jhanduta	Galian	0.885	0.567
	Behran	0.843	0.556
	Amroha	0.758	0.547
	Mean	0.828	0.557
Shri Naina Devi Ji	Dabheta	0.808	0.552
	Kutahla	0.762	0.534
	Kulah	0.801	0.551
	Mean	0.790	0.546
District Mean		0.783	0.544
District Range		0.673-0.885	0.509-0.574
Overall Mean		0.738	0.536
Overall Range		0.579-0.982	0.492-0.586

Yield of cauliflower crop in Bilaspur district varied from 172.6 to 212.5 q ha^{-1} with a meanvalue of 190.8 q ha^{-1}. Among villages, Loharwin village of Ghumarwin block recorded the highest yield (212.5 q ha^{-1}), whereas lowest yield was found in village Samari of Bilaspur Sadar block (172.6 q ha^{-1}). Among all blocks of Bilaspur district, Ghumarwin block recorded the highest (198.0 q ha^{-1}) and Bilaspur Sadar block recorded the lowest mean yield (176.3 q ha^{-1}).

In the overall studied area, the yield of cauliflower crop ranged from 155.8 to 228.5 q ha^{-1} with a mean value of 184.4 q ha^{-1}. The CV of 9.07 indicates that it varied spatially. Among districts, Bilaspur district recorded the highest mean yield of cauliflower crop (190.8 q ha^{-1}) and lowest mean yield of cauliflower crop was recorded in district Una (177.1 q ha^{-1}). This might be due to the reason that Bilaspur district is situated at higher elevation and average temperature in district Bilaspur remains lower as compared to the other districts which is favourable for curd development in cauliflower crop. Moreover, comparatively higher soil quality index (SQI) was also recorded in Bilaspur district than other two districts which means higher performance of soil quality indicators and better health of the soil which provide comparatively higher nutrients to the crop.

4.4 Nutrient concentration in cauliflower leaves

i. Macro nutrient concentration

a. Concentration of nitrogen, phosphorous and potassium

The data enumerated in the table 4.17 showed that in district Hamirpur total nitrogen, phosphorus and potassium content in the cauliflower leaves varied from 2.07 to 4.15, 0.46 to 0.85 and 2.03 to 3.47 per cent with mean values of 3.00, 0.70 and 2.89 per cent, respectively. The highest nitrogen, phosphorus and potassium content were observed in Bilkar Kahan, Bharmoti and Gulela villages of Bijhari, Nadaun and Bamson blocks, respectively. Lowest nitrogen and phosphorus content was recorded in Chaunki village of Sujanpur block while potassium content was recorded in Khagal village of Hamirpur block. Among different blocks of Hamirpur district, Bijhari (3.74 %), Nadaun (0.82 %) and Bijhari (3.35 %) blocks recorded the highest mean nitrogen, phosphorus and potassium content, respectively. Whereas, lowest mean nitrogen, phosphorus and potassium content were observed in Bhoranj (2.32 %), Sujanpur (0.62 %) and Hamirpur (2.46 %) blocks, respectively of Hamirpur district.

Table 4.16 Yield of cauliflower crop (q ha^{-1}) in open field conditions of sub-montane and subtropical zone of Himachal Pradesh

Block	Sites	Yield (q ha^{-1})
District- Hamirpur		
Bamson	Gulela	202.2
	Kangroo	210.6
	Halana	195.1
	Mean	202.6
Bhoranj	Jhandwin Changria	180.4
	Ghamarwin	185.3
	Bagwar	196.7
	Mean	187.5
Bijhari	Bilkar Kahan	228.5
	Patera	208.1
	Salan	212.8
	Mean	216.5
Hamirpur	Kakru	182.4
	Karahlar	162.1
	Khagal	158.4
	Mean	167.6
Nadaun	Bharmoti	157.5
	Mewli	180.4
	Kohla	167.2
	Mean	168.4
Sujanpur	Bhalana	158.6
	Tikkar	185.4
	Chaunki	178.4
	Mean	174.1
District Range		157.5-228.5
District Mean		186.1
District- Una		
Amb	Amb	186.3
	Pramb	168.5
	Heera Nagar	155.8
	Mean	170.2
Bangana	Malangar	180.5
	Amrera	165.3
	Surda	186.7
	Mean	177.5

Gagret	Dolatpur	175.0
	Ghanari	158.6
	Deoli	163.2
	Mean	165.6
Haroli	Shatarpur	205.7
	Ghaluwal	190.4
	Bhadsali	192.0
	Mean	196.0
Una	Fatehpur	188.8
	Sasan	172.0
	Lal Singhi	168.3
	Mean	176.4
District Range		155.8-205.7
District Mean		177.1
District- Bilaspur		
Bilaspur Sadar	Manman	175.4
	Panjel Khurd	180.9
	Samari	172.6
	Mean	176.3
Ghumarwin	Bhadrog	195.7
	Jahri	185.7
	Loharwin	212.5
	Mean	198.0
Jhanduta	Galian	202.4
	Behran	197.2
	Amroha	182.8
	Mean	194.1
Shri Naina Devi Ji	Dabheta	195.6
	Kutahla	190.7
	Kulah	198.5
	Mean	194.9
District Range		172.6-212.5
District Mean		190.8
Overall Mean		184.4
Overall Range		155.8-228.5
Standard Error		1.27
CV		9.07
Standard deviation		17.30

In Una district total nitrogen, phosphorus and potassium content in the cauliflower leaves varied from 2.28 to 3.94, 0.31 to 0.85 and 2.07 to 3.98 per cent with mean values of 3.10, 0.32 and 2.98 per cent, respectively. The highest nitrogen, phosphorus and potassium content were observed in Malangar, Pramb and Ghaluwal villages of Bangana, Amb and Haroli blocks, respectively, whereas lowest nitrogen, phosphorus and potassium content were recorded in Lal singhi, Ghaluwal, Amb village of Una, Haroli and Amb blocks, respectively. Among different blocks of Una district, Amb (3.40 %), Gagret (0.78 %) and Haroli (3.55 %) block recorded the highest mean nitrogen, phosphorus and potassium content, respectively. Whereas lowest mean nitrogen, phosphorus and potassium content were observed in Gagret (2.85 %), Haroli (0.35 %) and Amb (2.23 %) block, respectively.

In district Bilaspur, content of total nitrogen, phosphorus and potassium in cauliflower leaves varied from 2.54 to 3.98, 0.27 to 0.83 and 2.43 to 3.26 per cent with mean values of 3.16, 0.55 and 2.83 per cent, respectively. Galian village of Jhaduta block recorded the highest content of nitrogen and phosphorus, whereas potassium was found highest in Bhadrog village of Ghumarwin block. The lowest nitrogen content was observed in Manman village of Bilaspur Sadar block, whereas lowest phosphorus and potassium content were recorded in Kuthala and Kulah villages, respectively of Shri Naina Devi Ji block. Among different blocks of Bilaspur district Jhanduta block recorded the highest mean nitrogen and phosphorus content (3.46 and 0.68 %, respectively), while highest potassium content was observed in Bilaspur Sadar block (3.06 %).

Total nitrogen, phosphorus and potassium content in the cauliflower leaves in the overall studied area varied from 2.07 to 4.15, 0.27 to 0.85 and 2.03 to 3.98 per cent with overall mean values of 3.08, 0.63 and 2.90 per cent, respectively. In overall, the highest content of nitrogen, phosphorus and potassium in the cauliflower leaves were observed in Bilkar Kahan, Bharmoti and Ghaluwal villages of Bijhari, Nadaun and Haroli blocks of Hamirpur, Hamirpur and Una district, respectively. Whereas, the lowest nitrogen, phosphorus and potassium contents were observed in Chaunki, Kutahla and Khagal villages of Sujanpur, Shri Naina Devi Ji and Hamirpur blocks of Hamirpur, Bilaspur and Hamirpur district, respectively. The CV of 17.88, 30.00 and 15.15 per cent for leaf nitrogen, phosphorus and potassium content indicates that these varied spatially.

The sufficient concentration of leaf nitrogen, phosphorus and potassium may be ascribed to the medium availability of nitrogen and high availability of phosphorus and

Table 4.17 Content of total nitrogen, phosphorus and potassium (%) in cauliflower leaves

Block	Sites	N (%)	P (%)	K (%)
District- Hamirpur				
Bamson	Gulela	3.65	0.75	3.47
	Kangroo	4.02	0.61	3.25
	Halana	2.88	0.80	2.81
	Mean	3.52	0.72	3.18
Bhoranj	Jhandwin Changria	2.13	0.79	3.31
	Ghamarwin	2.08	0.52	2.44
	Bagwar	2.74	0.78	3.25
	Mean	2.32	0.70	3.00
Bijhari	Bilkar Kahan	4.15	0.81	3.41
	Patera	3.32	0.51	3.28
	Salan	3.74	0.61	3.37
	Mean	3.74	0.64	3.35
Hamirpur	Kakru	2.66	0.81	2.62
	Karahlar	2.71	0.79	2.74
	Khagal	3.48	0.48	2.03
	Mean	2.95	0.69	2.46
Nadaun	Bharmoti	2.15	0.85	2.82
	Mewli	3.35	0.77	3.01
	Kohla	2.56	0.83	2.26
	Mean	2.69	0.82	2.70
Sujanpur	Bhalana	3.28	0.84	2.15
	Tikkar	2.94	0.57	2.87
	Chaunki	2.07	0.46	2.99
	Mean	2.76	0.62	2.67
District Range		2.07-4.15	0.46-0.85	2.03-3.47
District Mean		3.00	0.70	2.89
District- Una				
Amb	Amb	3.15	0.80	2.07
	Pramb	3.84	0.85	2.12
	Heera Nagar	3.22	0.33	2.50
	Mean	3.40	0.66	2.23
Bangana	Malangar	3.94	0.52	3.07
	Amrera	2.55	0.81	3.62
	Surda	3.42	0.75	3.45
	Mean	3.30	0.69	3.38

Gagret	Dolatpur	3.32	0.84	3.11
	Ghanari	2.56	0.70	2.83
	Deoli	2.68	0.81	2.57
	Mean	2.85	0.78	2.84
Haroli	Shatarpur	3.55	0.36	3.24
	Ghaluwal	2.61	0.31	3.98
	Bhadsali	3.04	0.38	3.42
	Mean	3.07	0.35	3.55
Una	Fatehpur	3.26	0.82	2.77
	Sasan	3.11	0.61	3.09
	Lal Singhi	2.28	0.47	2.81
	Mean	2.88	0.63	2.89
District Range		2.28-3.94	0.31-0.85	2.07-3.98
District Mean		3.10	0.32	2.98
District- Bilaspur				
Bilaspur Sadar	Manman	2.54	0.41	3.05
	Panjel khurd	3.22	0.78	3.13
	Samari	2.68	0.79	3.01
	Mean	2.81	0.66	3.06
Ghumarwin	Bhadrog	2.74	0.49	3.26
	Jahri	3.36	0.41	2.78
	Loharwin	3.41	0.77	3.02
	Mean	3.17	0.56	3.02
Jhanduta	Galian	3.98	0.83	2.75
	Behran	3.34	0.42	2.61
	Amroha	3.05	0.79	2.52
	Mean	3.46	0.68	2.63
Shri Naina Devi Ji	Dabheta	3.87	0.32	2.80
	Kutahla	2.78	0.27	2.57
	Kulah	2.98	0.29	2.43
	Mean	3.21	0.29	2.60
District Range		2.54-3.98	0.27-0.83	2.43-3.26
District Mean		3.16	0.55	2.83
Overall Mean		3.08	0.63	2.90
Overall Range		2.07-4.15	0.27-0.85	2.03-3.98
Standard Error		0.32	0.24	0.26
CV		17.88	30.00	15.15
Standard Deviation		0.55	0.19	0.44

potassium in these soils to the plants. The observations are in agreement with those made by Thakur (1979), Campbell (2000) and Arshad (2020).

b. Concentration of sulphur, calcium and magnesium

An insight of the data in the table 4.18 revealed that in district Hamirpur, total sulphur, calcium and magnesium contents in the cauliflower leaves varied from 0.20 to 0.52, 1.13 to 2.05 and 0.32 to 0.74 per cent with mean values of 0.34, 1.47 and 0.60 per cent, respectively. The highest sulphur and calcium content were observed in Bilkar Kahan village, whereas magnesium was found to be highest in Salan village of Bhijari block. The lowest sulphur content was recorded in Bharmoti village of Nadaun block, whereas lowest calcium and magnesium contents were recorded in Kohla village of Nadaun block and Kakru village of Hamirpur block, respectively. Among different blocks of Hamirpur district, Bijhari block recorded the highest mean sulphur and calcium content (0.42 and 1.75 %, respectively), whereas mean magnesium content was found highest in Bhijari and Bamson block (0.69 %). The lowest mean sulphur, calcium and magnesium content were observed in Nadaun (0.23 %), Hamirpur and Sujanpur (1.30 %) and Hamirpur (0.45 %) blocks, respectively.

In Una district, total sulphur, calcium and magnesium content in the cauliflower leaves varied from 0.17 to 0.41, 1.29 to 2.02 and 0.32 to 0.80 per cent with mean values of 0.28, 0.32 and 0.61 per cent, respectively. The highest sulphur, calcium and magnesium contents were observed in Amb, Pramb and Ghaluwal villages of Amb, Amb and Haroli blocks, respectively, whereas lowest sulphur, calcium and magnesium contents were recorded in Deoli, Malangar, Amrera village of Gagret, Bangana and Bangana blocks, respectively. Among different blocks of Una district, Una and Haroli (0.33 %) block recorded the highest mean sulphur, whereas highest mean calcium and magnesium content were observed in Amb (1.74 %) and Una (0.72%), respectively. Whereas, lowest mean sulphur, calcium and magnesium contents were observed in Gagret (0.20 %), Bangana (1.43 %) and Amb (0.47 %) blocks, respectively.

In district Bilaspur, contents of total sulphur, calcium and magnesium in cauliflower leaves varied from 0.27 to 0.60, 1.18 to 1.89 and 0.35 to 0.79 per cent with mean values of 0.45, 1.44 and 0.63 per cent, respectively. Behran village of Jhanduta block, Galian village of Jhanduta block and Bhadrog villages of Ghumarwin block recorded the highest sulphur, calcium and magnesium contents, respectively. The lowest sulphur content was observed in Manman village of Bilaspur Sadar block, whereas lowest calcium and magnesium content

Table 4.18 Content of total sulphur, calcium and magnesium (%) in cauliflower leaves

Block	Sites	S (%)	Ca (%)	Mg (%)
District- Hamirpur				
Bamson	Gulela	0.37	1.51	0.69
	Kangroo	0.22	1.65	0.71
	Halana	0.45	1.62	0.67
	Mean	0.35	1.59	0.69
Bhoranj	Jhandwin Changria	0.29	1.39	0.66
	Ghamarwin	0.40	1.45	0.65
	Bagwar	0.44	1.58	0.68
	Mean	0.38	1.47	0.66
Bijhari	Bilkar Kahan	0.52	2.05	0.71
	Patera	0.33	1.51	0.63
	Salan	0.42	1.69	0.74
	Mean	0.42	1.75	0.69
Hamirpur	Kakru	0.43	1.38	0.32
	Karahlar	0.32	1.31	0.45
	Khagal	0.46	1.21	0.58
	Mean	0.40	1.30	0.45
Nadaun	Bharmoti	0.20	1.37	0.63
	Mewli	0.28	1.68	0.68
	Kohla	0.22	1.13	0.40
	Mean	0.23	1.39	0.57
Sujanpur	Bhalana	0.21	1.22	0.42
	Tikkar	0.27	1.42	0.64
	Chaunki	0.32	1.25	0.55
	Mean	0.27	1.30	0.54
District Range		0.20-0.52	1.13-2.05	0.32-0.74
District Mean		0.34	1.47	0.60
District- Una				
Amb	Amb	0.41	1.35	0.41
	Pramb	0.19	2.02	0.54
	Heera Nagar	0.31	1.85	0.47
	Mean	0.30	1.74	0.47
Bangana	Malangar	0.20	1.29	0.68
	Amrera	0.37	1.58	0.32
	Surda	0.21	1.41	0.64
	Mean	0.26	1.43	0.55
Gagret	Dolatpur	0.22	1.38	0.54
	Ghanari	0.20	1.68	0.68

	Deoli	0.17	1.52	0.60
	Mean	0.20	1.53	0.61
Haroli	Shatarpur	0.29	1.65	0.65
	Ghaluwal	0.32	1.43	0.80
	Bhadsali	0.38	1.48	0.64
	Mean	0.33	1.52	0.70
Una	Fatehpur	0.34	1.32	0.70
	Sasan	0.32	1.93	0.68
	Lal Singhi	0.33	1.49	0.78
	Mean	0.33	1.58	0.72
District Range		0.17-0.41	1.29-2.02	0.32-0.80
District Mean		0.28	0.32	0.61
District- Bilaspur				
Bilaspur Sadar	Manman	0.27	1.27	0.75
	Panjel khurd	0.35	1.61	0.51
	Samari	0.31	1.62	0.60
	Mean	0.31	1.50	0.62
Ghumarwin	Bhadrog	0.49	1.25	0.79
	Jahri	0.58	1.29	0.62
	Loharwin	0.40	1.49	0.72
	Mean	0.49	1.34	0.71
Jhanduta	Galian	0.52	1.89	0.58
	Behran	0.60	1.33	0.73
	Amroha	0.47	1.18	0.35
	Mean	0.53	1.47	0.55
Shri Naina Devi Ji	Dabheta	0.52	1.42	0.68
	Kutahla	0.48	1.55	0.53
	Kulah	0.42	1.32	0.69
	Mean	0.47	1.43	0.63
District Range		0.27-0.60	1.18-1.89	0.35-0.79
District Mean		0.45	1.44	0.63
Overall Mean		0.35	1.49	0.61
Overall Range		0.17-0.60	1.13-2.05	0.32-0.80
Standard Error		0.19	0.18	0.16
CV		31.29	14.77	19.64
Standard Deviation		0.11	0.22	0.12

were recorded in Amroha village of Jhanduta block. Bilaspur Sadar, Ghumarwin, Jhanduta and Shri Naina Devi Ji recorded 0.31, 0.49, 0.53 and 0.47 per cent of sulphur content, respectively, 1.50, 1.34, 1.47 and 1.43 per cent of calcium content and 0.62, 0.71, 0.55 and 0.63 per cent magnesium content, respectively.

In overall studied area, the content of sulphur, calcium and magnesium in the cauliflower leaves ranged from 0.17 to 0.60, 1.13 to 2.05 and 0.32 to 0.80 per cent with overall mean values of 0.35, 1.49 and 0.61 per cent, respectively. The lowest content of sulphur and calcium in the cauliflower leaves were observed in Deoli and Kohla villages of Gagret and Nadaun blocks of Una and Hamirpur districts, respectively, whereas lowest magnesium content was observed in Kakru and Amrera villages of Hamirpur and Bangana blocks in Hamirpur and Una districts, respectively. The highest sulphur, calcium and magnesium contents were observed in Behran, Bilkar Kahan and Ghaluwal villages of Jhanduta, Bhijari and Haroli blocks of Bilaspur, Hamirpur and Una district, respectively. The CV of 31.29, 14.77 and 19.64 per cent for leaf sulphur, calcium and magnesium indicates that these varied spatially. Sulphur content was found deficient in most of the leaf samples, calcium content was recorded medium, whereas magnesium content was observed in high concentration in leaf samples of cauliflower.

ii. Micro-nutrient concentration

Data pertaining to iron, zinc, copper and manganese content of cauliflower leaves is presented in table 4.19. Perusal of the data revealed that in district Hamirpur, total iron, zinc, copper and manganese contents in the cauliflower leaves varied from 115.24 to 277.65, 36.74 to 70.48, 30.76 to 54.12 and 53.45 to 95.41 ppm with mean values of 181.47, 52.52, 40.38 and 74.46 ppm, respectively. Patera and Bilkar Kahan villages in Bhijari block recorded highest iron and zinc content, while highest copper and manganese content were found in Ghamarwin and Gulela villages of Bhoranj and Bamson block, respectively. The lowest iron, zinc, copper and manganese content were recorded in Bhalana, Kohla, Karahlar and Bhalana villages of Sujanpur, Nadaun, Hamirpur and Sujanpur blocks, respectively. Among different blocks of Hamirpur district, Bhijari block recorded highest mean iron, zinc and manganese content whereas highest mean copper was observed in Bhoranj block.

In district Una total iron, zinc, copper and manganese contents in the cauliflower leaves varied from 90.78 to 188.45, 23.45 to 62.85, 25.40 to 38.26 and 48.52 to 92.22 ppm with mean values of 131.22, 38.11, 29.76 and 64.52 ppm, respectively. The highest iron, zinc,

Table.4.19 Content of micronutrients (ppm) in cauliflower leaves

Block	Sites	Fe	Zn	Cu	Mn
District- Hamirpur					
Bamson	Gulela	186.17	68.41	36.41	95.41
	Kangroo	212.25	64.36	35.56	79.54
	Halana	197.85	42.15	50.25	72.85
	Mean	198.76	58.31	40.74	82.60
Bhoranj	Jhandwin Changria	172.40	69.35	45.85	78.32
	Ghamarwin	152.65	39.45	54.12	75.41
	Bagwar	202.41	55.12	52.32	64.79
	Mean	175.82	54.64	50.76	72.84
Bijhari	Bilkar Kahan	200.12	70.48	36.85	90.23
	Patera	277.65	65.25	43.12	86.21
	Salan	195.74	63.89	53.25	91.47
	Mean	224.50	66.54	44.41	89.30
Hamirpur	Kakru	185.52	64.74	33.27	58.10
	Karahlar	178.95	42.15	30.76	71.25
	Khagal	162.34	36.84	39.65	69.74
	Mean	175.60	47.91	34.56	66.36
Nadaun	Bharmoti	175.53	40.14	35.22	57.47
	Mewli	192.45	41.65	42.85	76.25
	Kohla	152.35	36.74	36.69	82.20
	Mean	173.44	39.51	38.25	71.97
Sujanpur	Bhalana	115.24	46.74	31.20	53.45
	Tikkar	147.85	52.45	37.42	82.20
	Chaunki	158.95	45.36	32.05	55.41
	Mean	140.68	48.18	33.56	63.69
District Range		115.24-277.65	36.74-70.48	30.76-54.12	53.45-95.41
District Mean		181.47	52.52	40.38	74.46
District- Una					
Amb	Amb	112.65	62.85	29.74	52.14
	Pramb	138.45	53.41	28.45	59.45
	Heera Nagar	125.65	27.12	31.41	62.74
	Mean	125.58	47.79	29.87	58.11
Bangana	Malangar	111.70	37.85	25.40	81.25
	Amrera	135.65	49.32	27.96	92.22
	Surda	147.54	36.41	28.45	84.87
	Mean	131.63	41.19	27.27	86.11
Gagret	Dolatpur	179.85	35.25	31.44	77.41
	Ghanari	188.45	28.74	30.25	48.52
	Deoli	132.98	45.12	28.74	52.41

	Mean	167.09	36.37	30.14	59.45
Haroli	Shatarpur	105.45	34.15	34.56	53.65
	Ghaluwal	95.23	23.45	28.55	56.41
	Bhadsali	90.78	26.14	29.85	51.85
	Mean	97.15	27.91	30.99	53.97
Una	Fatehpur	154.26	46.25	38.26	72.41
	Sasan	127.45	33.41	27.41	63.55
	Lal Singhi	122.25	32.14	25.98	58.95
	Mean	134.65	37.27	30.55	64.97
District Range		90.78-188.45	23.45-62.85	25.40-38.26	48.52-92.22
District Mean		131.22	38.11	29.76	64.52
District- Bilaspur					
Bilaspur Sadar	Manman	103.28	40.74	32.25	60.25
	Panjel Khurd	137.54	29.85	40.87	84.87
	Samari	123.97	25.41	34.25	70.14
	Mean	121.60	32.00	35.79	71.75
Ghumarwin	Bhadrog	192.47	33.45	33.41	92.45
	Jahri	176.25	36.47	55.28	65.25
	Loharwin	145.68	27.41	31.96	79.49
	Mean	171.47	32.44	40.22	79.06
Jhanduta	Galian	158.12	41.65	30.74	93.41
	Behran	147.63	53.47	52.45	84.87
	Amroha	172.85	37.81	29.33	87.14
	Mean	159.53	44.31	37.51	88.47
Shri Naina Devi Ji	Dabheta	132.41	32.29	28.23	79.52
	Kutahla	125.36	22.14	35.16	68.81
	Kulah	156.41	36.12	34.75	65.41
	Mean	138.06	30.18	32.71	71.25
District Range		103.28-192.47	22.14-53.47	28.23-55.28	60.25-93.41
District Mean		147.66	34.73	36.56	77.63
Overall Mean		155.71	42.97	35.82	71.99
Overall Range		90.78-277.65	22.14-70.48	25.40-55.28	48.52-95.41
Standard Error		9.95	2.06	1.38	1.61
CV		23.62	31.39	22.86	18.92
Standard Deviation		36.77	13.49	8.19	13.62

copper and manganese contents were recorded in Ghanari, Amb, Fatehpur and Amrera villages of Gagret, Amb, Una and Bangana blocks, respectively. The lowest iron, zinc, copper and manganese contents were recorded in Bhadsali, Ghaluwal, Malangar and Ghanari villages of Haroli, Haroli, Bangana and Gagret block, respectively. Among different blocks of Una district Gagret, Amb, Haroli and Bangana blocks recorded highest mean iron, zinc, copper and manganese content, respectively.

In district Bilaspur total iron, zinc, copper and manganese content in the cauliflower leaves varied from 103.28 to 192.47, 22.14 to 53.47, 28.23 to 55.28 and 60.25 to 93.41 ppm with mean values of 147.66, 34.73, 36.56 and 77.63 ppm, respectively. The highest iron and copper contents were recorded in Bhadrog and Jahri villages of Ghumarwin block, whereas highest zinc and manganese content were found in Behran and Galian villages of Jhanduta block. The lowest iron and manganese content were recorded in Manman village of Bilaspur Sadar block, whereas zinc and copper contents were found lowest in Kutahla and Dabheta villages of Shri Naina Devi Ji block. Among different blocks of Bilaspur district, Ghumarwin block recorded highest mean iron and copper content, whereas highest mean zinc and manganese content were recorded in Jhanduta block.

In overall studied area the contents of iron, zinc, copper and manganese in the cauliflower leaves ranged from 90.78 to 277.65, 22.14 to 70.48, 25.40 to 55.28 and 48.52 to 95.41 ppm with overall mean values of 155.71, 42.97, 35.82 and 71.99 ppm, respectively. The lowest content of iron, zinc, copper and manganese in the cauliflower leaves were observed in Bhadsali, Kutahla, Malangar and Ghanari villages of Haroli, Shri Naina Devi Ji, Bangana and Gagret blocks of Una, Bilaspur, Una and Una districts, respectively. Whereas, the highest iron, zinc, copper and manganese contents were observed in Patera, Bilkar Kahan, Jahri and Gulela villages of Bhijari, Bhijari, Ghumarwin and Bamson blocks of Hamirpur, Hamirpur, Bilaspur and Hamirpur districts, respectively. The CV of 23.62, 31.39, 22.86 and 18.92 per cent for leaf iron, zinc, copper and manganese indicates that these varied spatially. Zinc and manganese were found medium whereas, iron and copper were observed to be high in concentration in leaf samples

4.5 Relationship among soil properties and crop productivity

4.5.1 Relationship among soil characteristics

The data presented in the table 4.20 on the relationship of soil characteristics with the available soil nutrient content stated that the sand content was found to have highest significant and positive correlation with bulk density (0.644*) and highest negative correlation with silt content (-0.977**). The sand content had non-significant relations with all the soil properties except silt content (-0.977**), clay content (-0.548**), bulk density (0.644**), maximum water holding capacity (-0.544**) and magnesium content (-0.319*). The results were in accordance with Chaudhari *et al.* (2013) who also reported positive correlation of bulk density with sand content (r=0.9094). The silt content also showed non-significant relationship with all the soil properties excluding sand content (-0.977*), clay content (0.359*), bulk density (-0.657**) and maximum water holding capacity (0.527**). Silt content had a highest significant positive and negative correlation with maximum water holding capacity (0.527**) and sand (-0.977**), respectively. The highest significant positive correlation for the clay content was found with silt content (0.359**) and highest negative correlation with sand content (-0.548**). A non-significant correlation of clay content was recorded between all the soil properties except for the sand content (-0.548**), silt content (0.359*), maximum water holding capacity (0.318*), calcium content (0.295*) and magnesium content (0.306*).

Bulk density showed non-significant relationships with all the soil properties except for the sand content (0.644**), silt content (-0.657**), maximum water holding capacity (-0.825**), organic carbon content (-0.369**), exchangeable magnesium content (-0.346*), microbial biomass carbon content (-344*) and microbial biomass nitrogen content (-0.295*). The results are in trend line with the findings of Mahajan *et al.* (2007) who also reported the significant negative relationship between bulk density and organic carbon. A negative correlation (r = -0.886*) between the organic matter and bulk density was also reported by Chaudhari *et al.* (2013). The results were further in accordance with Kumar and Paliyal (2016) who recorded a negative and non-significant correlation of bulk density with available nitrogen, phosphorous and sulphur. The maximum water holding capacity showed a highly significant and negative correlation with bulk density (-0.825 **) and highest significant positive correlation with silt content (0.527**).

Among chemical properties of the soil, pH showed a non-significant relationship with all the soil properties except for the EC (0.517**), available phosphorous (-0.394**), DTPA-extractable copper (-0.348*), DTPA-extractable manganese (-0.648**), DTPA-extractable iron (-0.739**), DTPA-extractable zinc (-0.552**) and soil respiration (-0.448**). Soil electrical conductivity showed a non-significant relationship with all the

Table 4.20 Simple correlation coefficient (r) between different soil properties under cultivated conditions of sub-montane and subtropical zone of HP

	sand	silt	clay	BD	MWHC	pH	EC	OC	N	P	K	S	Ca	Mg	Cu	Mn	Fe	Zn	MBC	MBN	S R
Sand	1																				
Silt	-0.977**	1																			
Clay	-0.548**	0.359*	1																		
BD	0.644**	-0.657**	-0.245^{NS}	1																	
MWHC	-0.544**	0.527**	0.318*	-0.825**	1																
pH	-0.123^{NS}	0.109^{NS}	0.114^{NS}	0.011^{NS}	-0.006^{NS}	1															
EC	-0.204^{NS}	0.203^{NS}	0.098^{NS}	-0.152^{NS}	-0.002^{NS}	0.517**	1														
OC	-0.074^{NS}	0.068^{NS}	0.061^{NS}	-0.369*	0.420**	-0.130^{NS}	0.017^{NS}	1													
N	0.125^{NS}	-0.119^{NS}	-0.083^{NS}	0.000^{NS}	0.136^{NS}	-0.138^{NS}	0.069^{NS}	0.579**	1												
P	0.141^{NS}	-0.083^{NS}	-0.292^{NS}	0.135^{NS}	-0.154^{NS}	-0.394**	-0.281^{NS}	0.116^{NS}	0.140^{NS}	1											
K	-0.263^{NS}	0.252^{NS}	0.166^{NS}	-0.245^{NS}	0.087^{NS}	-0.129^{NS}	0.060^{NS}	0.369*	0.079^{NS}	-0.192^{NS}	1										
S	-0.019^{NS}	0.008^{NS}	0.053^{NS}	-0.243^{NS}	0.430**	-0.079^{NS}	-0.085^{NS}	0.629**	0.191^{NS}	-0.224^{NS}	-0.011^{NS}	1									
Ca	-0.266^{NS}	0.222^{NS}	0.295*	0.039^{NS}	0.106^{NS}	0.029^{NS}	0.050^{NS}	0.279^{NS}	0.338*	-0.006^{NS}	0.217^{NS}	-0.021^{NS}	1								
Mg	-0.319*	0.279^{NS}	0.306*	-0.346*	0.232^{NS}	-0.037^{NS}	0.063^{NS}	0.417**	0.149^{NS}	-0.254^{NS}	0.502**	0.122^{NS}	0.247^{NS}	1							
Cu	-0.073^{NS}	0.106^{NS}	-0.099^{NS}	-0.219^{NS}	0.136^{NS}	-0.348*	-0.036^{NS}	0.299*	-0.058^{NS}	-0.025^{NS}	0.017^{NS}	0.381**	0.043^{NS}	0.274^{NS}	1						
Mn	0.224^{NS}	-0.264^{NS}	0.053^{NS}	0.026^{NS}	0.041^{NS}	-0.648**	-0.371*	0.547**	0.408**	0.130^{NS}	0.368*	0.367*	0.051^{NS}	0.202^{NS}	0.338*	1					
Fe	0.114^{NS}	-0.081^{NS}	-0.184^{NS}	-0.120^{NS}	0.068^{NS}	-0.739**	-0.504**	0.324*	0.176^{NS}	0.350*	0.099^{NS}	0.235^{NS}	0.083^{NS}	0.192^{NS}	0.458**	0.571**	1				
Zn	0.086^{NS}	-0.055^{NS}	-0.161^{NS}	0.032^{NS}	-0.009^{NS}	-0.552**	-0.367*	0.322*	0.286^{NS}	0.308*	0.044^{NS}	0.093^{NS}	0.174^{NS}	0.034^{NS}	0.285^{NS}	0.360*	0.486**	1			
MBC	-0.044^{NS}	0.044^{NS}	0.017^{NS}	-0.344*	0.402**	-0.088^{NS}	0.020^{NS}	0.842**	0.454**	-0.063^{NS}	0.179^{NS}	0.758**	0.150^{NS}	0.288^{NS}	0.378*	0.469**	0.275^{NS}	0.167^{NS}	1		
MBN	-0.074^{NS}	0.034^{NS}	0.191^{NS}	-0.295*	0.257^{NS}	-0.110^{NS}	0.006^{NS}	0.763**	0.365*	-0.234^{NS}	0.488**	0.442**	0.220^{NS}	0.527**	0.210^{NS}	0.485**	0.283^{NS}	0.099^{NS}	0.660**	1	
S R	-0.007^{NS}	-0.006^{NS}	0.056^{NS}	-0.224^{NS}	0.285^{NS}	-0.448**	-0.150^{NS}	0.657**	0.283^{NS}	-0.001^{NS}	0.204^{NS}	0.509**	0.313*	0.259^{NS}	0.455**	0.417**	0.532**	0.571**	0.630**	0.474**	1

**. Significant at the 0.01 level

*. Significant at the 0.05 level

soil properties except for soil pH (0.517**), DTPA-extractable manganese (-0.371*), DTPA-extractable iron (-0.504**) and DTPA-extractable zinc (-0.367*). The organic carbon content was found to have highly significant and positive correlation with microbial biomass carbon content (0.842**). Similar significant and positive correlation between organic carbon and microbial biomass carbon content was recorded by Chandel (2013). Soil organic carbon also showed significant and positive correlation with the maximum water holding capacity (0.420**), available nitrogen (0.579*), potassium (0.369*), sulphur (0.629**), exchangeable magnesium (0.417**) and DTPA-extractable iron (0.324*), copper (0.299*), zinc (0.322*) and manganese (0.547**), microbial biomass nitrogen (0.763**) and soil respiration (0.657**). Similar findings were also reported by Kakar (2014), Nath and Bhattachayya (2014), Singh *et al*. (2014), Gyawali *et al.* (2016), Annepu *et al*. (2017) and Kumar *et al.* (2017).

Among macronutrients, it was observed from the correlation studies that available nitrogen was positively and significantly correlated with the organic carbon content (0.579**), microbial biomass carbon (0.454**), exchangeable calcium (0.338*), microbial biomass nitrogen (0.365*) and DTPA-extractable manganese (0.408**). The available phosphorous showed a non-significant relation with all the soil properties except for pH (-0.394**), DTPA-extractable iron (0.350*) and zinc (0.308*). The results were in accordance with the Ramana *et al.* (2015) who reported the non-significant relationship between bulk density and available phosphorous content. Available potassium was highly significantly and positively correlated with magnesium content (0.502**) followed by microbial biomass nitrogen (0.488**). Available sulphur was also found to be highly significantly and positively correlated with microbial biomass carbon content (0.758**). Similar results were reported by Ramana *et al.* (2015) who revealed the positive and non-significant relationships of sulphur with maximum water holding capacity.

Exchangeable calcium was observed to have non significant relationship with all the properties except for clay content (0.295*), available nitrogen content (0.338*) and soil respiration (0.313*). Exchangeable magnesium showed a highly significant and positive correlation with microbial biomass nitrogen (0.527**), available potassium (0.502**) and organic carbon content (0.417**) and the results were in similarity with the findings of Mahajan *et al.* (2007), Shetty *et al.* (2008) who reported the significantly positive relationship of exchangeable magnesium with organic carbon and available potassium.

DTPA-extractable micronutrients showed a non-significant correlation with sand, silt, clay, bulk density and maximum water holding capacity, exchangeable calcium and magnesium. Highest significant and positive correlation of DTPA-extractable iron, copper, zinc and manganese was recorded with manganese content (0.571**), iron content (0.458**), soil respiration (0.571**) and iron content (0.571**), respectively. A negative and significant correlation between soil pH and micronutrients was observed. DTPA-extractable Fe and zinc were found to be positively and significantly correlated with soil organic carbon, while relation with pH was negative in nature. Katyal and Sharma (1991) found a significant positive correlation of extractable Fe and zinc content with soil organic carbon content and a negative relationship with soil pH in acid, alkaline and neutral soils. Mahajan *et al.* (2007) also reported positive correlations between the DTPA-extractable copper, zinc and manganese with the organic carbon content.

Among microbiological properties, microbial biomass carbon and microbial biomass nitrogen were positively significantly correlated with organic carbon content (0.842** and 0.763**, respectively) and negatively correlated with bulk density (-0.344* and -0.295*, respectively). Soil respiration had highest significant correlation with organic carbon content (0.657**) followed by microbial biomass carbon (0.630**).

4.5.2 Relationship of soil properties with yield and nutrient content of leaves

Critical analysis of the data in table 4.21 gives a clear view of correlation between the soil properties and yield of cauliflower crop and also, correlation between the soil properties and nutrient content of the cauliflower leaves. The data in the table shows that the yield of cauliflower crop was highly significantly correlated with organic carbon content (0.957**) and significantly but negatively correlated with bulk density (-0.449**). Similar results were also observed by Chandel (2013) who also observed that the crop yield registered positive relationship with all soil properties except bulk density, pH and EC.

The correlation studies shows that the leaf nitrogen was significantly and positively correlated with the available nitrogen content (0.977**) followed by organic carbon content (0.544**), microbial biomass carbon (0.445**), manganese (0.386**), microbial biomass nitrogen (0.370*) and calcium (0.345*) and had non-significant relationship with all the other soil properties. The highest significant and positive correlation of leaf phosphorous was found with the available phosphorous content of the soil (0.614**). The results of the present investigation are in close proximity with the findings of Priya *et al.*

Table 4.21 Simple correlation coefficient (r) between different soil properties, yield and leaf nutrient status

Soil/leaf	Yield	N	P	K	S	Ca	Mg	Fe	Zn	Cu	Mn
Sand	-0.165^{NS}	0.153^{NS}	0.128^{NS}	-0.303*	0.024^{NS}	-0.200^{NS}	-0.282^{NS}	0.073^{NS}	0.156^{NS}	-0.093^{NS}	0.262^{NS}
Silt	0.168^{NS}	-0.152^{NS}	-0.133^{NS}	0.290^{NS}	-0.033^{NS}	0.150^{NS}	0.243^{NS}	-0.042^{NS}	-0.117^{NS}	0.130^{NS}	-0.294*
Clay	0.064^{NS}	-0.072^{NS}	-0.039^{NS}	0.189^{NS}	0.028^{NS}	0.289^{NS}	0.286^{NS}	-0.158^{NS}	-0.228^{NS}	-0.104^{NS}	0.008^{NS}
BD	-0.449**	0.038^{NS}	0.203^{NS}	-0.266^{NS}	-0.189^{NS}	0.082^{NS}	-0.309*	-0.098^{NS}	0.058^{NS}	-0.227^{NS}	0.003^{NS}
MWHC	0.438**	0.119^{NS}	-0.095^{NS}	0.105^{NS}	0.371*	0.105^{NS}	0.217^{NS}	0.024^{NS}	-0.057^{NS}	0.173^{NS}	0.066^{NS}
pH	-0.194^{NS}	-0.091^{NS}	-0.457**	-0.118^{NS}	-0.067^{NS}	-0.014^{NS}	0.011^{NS}	-0.648**	-0.620**	-0.351*	-0.544**
EC	-0.010^{NS}	0.098^{NS}	-0.302*	0.066^{NS}	-0.090^{NS}	0.013^{NS}	0.111^{NS}	-0.471**	-0.354*	-0.050^{NS}	-0.287^{NS}
OC	0.957**	0.554**	-0.173^{NS}	0.416**	0.585**	0.274^{NS}	0.338*	0.299*	0.286^{NS}	0.284^{NS}	0.530**
N	0.528**	0.977**	0.017^{NS}	0.080^{NS}	0.156^{NS}	0.367*	0.140^{NS}	0.122^{NS}	0.293^{NS}	-0.053^{NS}	0.413**
P	0.082^{NS}	0.126^{NS}	0.614**	-0.200^{NS}	-0.193^{NS}	-0.011^{NS}	-0.288^{NS}	0.285^{NS}	0.338*	0.025^{NS}	0.102^{NS}
K	0.389**	0.031^{NS}	-0.095^{NS}	0.983**	-0.050^{NS}	0.184^{NS}	0.439**	0.095^{NS}	0.050^{NS}	-0.006^{NS}	0.292^{NS}
S	0.536**	0.213^{NS}	-0.288^{NS}	0.011^{NS}	0.985**	0.014^{NS}	0.110^{NS}	0.166^{NS}	0.046^{NS}	0.411**	0.380*
Ca	0.256^{NS}	0.345*	0.098^{NS}	0.254^{NS}	-0.045^{NS}	0.976**	0.225^{NS}	0.084^{NS}	0.128^{NS}	0.008^{NS}	-0.005^{NS}
Mg	0.527**	0.127^{NS}	-0.277^{NS}	0.516**	0.077^{NS}	0.186^{NS}	0.954**	0.177^{NS}	0.032^{NS}	0.239^{NS}	0.119^{NS}
Cu	0.343*	-0.067^{NS}	-0.012^{NS}	0.022^{NS}	0.383**	0.002^{NS}	0.257^{NS}	0.461**	0.348*	0.972**	0.284^{NS}
Mn	0.508**	0.386**	0.234^{NS}	0.383**	0.327*	0.100^{NS}	0.148^{NS}	0.505**	0.386**	0.322*	0.946**
Fe	0.360*	0.167^{NS}	0.337*	0.136^{NS}	0.203^{NS}	0.087^{NS}	0.099^{NS}	0.916**	0.531**	0.474**	0.494**
Zn	0.380*	0.199^{NS}	0.368*	0.075^{NS}	0.099^{NS}	0.162^{NS}	-0.069^{NS}	0.502**	0.975**	0.255^{NS}	0.262^{NS}
MBC	0.779**	0.445**	-0.336*	0.218^{NS}	0.725**	0.160^{NS}	0.291^{NS}	0.233^{NS}	0.134^{NS}	0.394**	0.490**
MBN	0.741**	0.370*	-0.259^{NS}	0.522**	0.410**	0.241^{NS}	0.470**	0.312*	0.079^{NS}	0.197^{NS}	0.457**
SR	0.642**	0.270^{NS}	0.046^{NS}	0.242^{NS}	0.483**	0.351*	0.208^{NS}	0.392**	0.415**	0.516**	0.509**

**. Significant at the 0.01 level, *. Significant at the 0.05 level

(2007). Leaf potassium was highly significantly correlated with soil available potassium (0.983**). In case of leaf potassium, the significant and negative correlation was recorded with sand content (-0.303*). The highest significant and positive relationship of leaf sulphur, calcium and magnesium was recorded with available sulphur (0.985**), exchangeable calcium (0.976**) and exchangeable magnesium (0.954**), respectively.

In case of micronutrients, the leaf iron content was highly significantly and positively correlated with the DTPA-extractable iron (0.916**). DTPA-extractable iron was observed to be highly significantly but negatively correlated with pH (-0.648**). In case of leaf zinc content, highly significantly and positive correlations was observed with DTPA-extractable zinc (0.975**) followed by iron (0.531**), soil respiration (0.415**) and manganese (0.386**), copper (348*) and available phosphorous (0.338*) whereas, it was significantly but negatively correlated with soil pH (-0.620**). The highest significant and positive correlation of leaf copper was found with DTPA-extractable copper (0.972**) followed by soil respiration (0.516**), iron (0.474**), available sulphur (0.411**), microbial biomass carbon content (0.394**) and manganese (0.322*). The leaf manganese was observed to be highly significantly and positively correlated with the DTPA-extractable manganese (0.946**). The results were in testimony with the findings of Mogta and Sharma (2018) who found that plant manganese had positive correlation with DTPA-extractable manganese in soil and plant copper content was positively correlated with DTPA-extractable copper content in soil.

Chapter-5

SUMMARY AND CONCLUSIONS

The present investigation entitled **"Assessment of soil health under vegetable cultivation in sub-montane and subtropical zone of Himachal Pradesh"** was carried out during 2020-2021 in Hamirpur, Una and Bilaspur districts of Himachal Pradesh with the objectives to assess the effect of vegetable cultivation on soil health and to determine the correlation among soil properties and crop productivity. Soil samples at a depth of 0-15 cm were collected from forty-five locations in fifteen blocks of Hamirpur, Una and Bilaspur districts during the months of September, 2020. The soil samples from uncultivated area within the selected field under study (termed as buffer) were also collected to fulfil the objectives of the present investigation. A survey was carried out in vegetable growing areas of the zone for assortment of necessary information about cultivation practices and cropping patterns. Soil samples collected from the various sites from cultivated and buffer conditions were analysed for physical, chemical and microbiological properties by adopting standard methods. A total of 19 indicators were considered for soil quality assessment including the physical indicators (texture, bulk density and maximum water holding capacity), chemical indicators were (pH, electrical conductivity, organic carbon, soil available N, P, K, S exchangeable calcium and magnesium and DTPA-extractable micronutrient Fe, Zn, Cu and Mn) and microbiological properties (microbial biomass carbon and nitrogen and soil respiration). Data reduction technique was used to identify the key indicators contributing towards soil quality and integrating those indicators into a index, to finally calculate the index. For this principal component analysis was used as a tool to reduce the large data set to minimum data set (MDS). The salient findings that emerged out from the present investigation are summarised as under:

5.1 Status of physico-chemical and microbiological properties of soil

5.1.1 Physical properties

The soil texture under various sites selected under present study varied from sandy loam to loam, however, sandy loam was observed as the most dominant texture under both cultivated and buffer conditions. The bulk density and maximum water holding capacity under cultivated conditions in the overall study area ranged from 1.20 to 1.43 Mg m^{-3} and 40.2 to 54.2 per cent, respectively. Whereas, under buffer conditions, bulk density and maximum water holding capacity varied from 1.23 to 1.46 Mg m^{-3} and 37.2 to 51.8 per cent, respectively. Comparatively lower bulk density was observed under cultivated conditions (1.31 Mg m^{-3}) over buffer conditions (1.34 Mg m^{-3}) and average maximum water holding capacity was found higher under cultivated conditions (45.5 per cent) as compared to buffer conditions (43.2 per cent).

5.1.2 Chemical properties

Soil reaction across various sites under present study was neutral to slightly saline in nature. Overall soil pH varied between 6.50 to 7.64 under cultivated conditions and 6.47 to 7.59 under buffer conditions with mean values of 7.08 and 7.03, respectively. Electrical conductivity was observed to be in safe limits and ranged between 0.154 to 0.287 dS m^{-1} with a mean value of 0.205 dS m^{-1} under cultivated conditions whereas, under buffer condition it varied from 0.124 to 0.267 dS m^{-1} with a mean value of 0.190 dS m^{-1} in overall studied area. Organic carbon under cultivated conditions varied from 6.8 to 17.2 g kg^{-1}, while it ranged between 4.5 to 7.0 g kg^{-1} under buffer conditions. In general, comparatively higher organic carbon was observed under cultivated conditions over buffer conditions with overall mean values of 10.8 and 5.6 g kg^{-1}, respectively.

The available nitrogen content of soils under cultivated conditions in the overall studied area varied from 245.3 to 416.6 kg ha^{-1}, whereas, in buffer conditions it ranged from 178.5 to 312.3 kg ha^{-1}. The available phosphorous content ranged from 40.2 to 65.7 kg ha^{-1} in soils under vegetable cultivation, whereas in buffer conditions it varied from 17.3 to 24.2 kg ha^{-1} in the overall studied area. The available potassium of soils in overall studied area under cultivated conditions varied from 147.2 to 546.1 kg ha^{-1}, whereas, in buffer conditions it ranged from 117.7 to 315.7 kg ha^{-1} Overall mean available nitrogen, phosphorous and potassium content were found lower (223.7, 21.5 and 248.0 kg ha^{-1}, respectively) under buffer conditions as compared to cultivated conditions (332.2, 55.2 and 317.4 kg ha^{-1}, respectively).

In overall study area, available sulphur content varied from 8.4 to 20.3 kg ha^{-1} with a mean value of 13.5 kg ha^{-1} under cultivated conditions, whereas in buffer conditions it varied from 6.5 to 14.6 kg ha^{-1} with a mean value of 10.3 kg ha^{-1}. The exchangeable calcium of soils under cultivated conditions varied from 3.20 to 9.50 c mol (p^+) kg^{-1} whereas, under buffer conditions it ranged from 2.88 to 8.90 c mol (p^+) kg^{-1} in overall studied area. The exchangeable magnesium content of soils in the overall studied area under cultivated conditions varied from 1.08 to 2.71 c mol (p^+) kg^{-1} with a mean value of 1.98 c mol (p^+) kg^{-1}, while under buffer conditions it ranged from 0.75 to 2.47 c mol (p^+) kg^{-1} with a mean value of 1.63 c mol (p^+) kg^{-1}. Mean exchangeable calcium and magnesium was found higher in cultivated conditions as compared to buffer conditions.

Available sulphur was found deficient in all the soils, available nitrogen and potassium were observed in medium to high range and available phosphorous, exchangeable calcium and magnesium were found high in status.

The DTPA-extractable iron, zinc, copper and manganese content of soils under cultivated conditions varied from 5.56 to 14.35, 0.92 to 1.98, 0.63 to 2.18 and 1.64 to 3.54 mg kg^{-1}, respectively with a mean value of 9.89, 1.39, 1.14 and 2.46 mg kg^{-1}, respectively in the overall studied area. In buffer conditions DTPA-extractable iron, zinc, copper and manganese content of soils ranged from 4.96 to 12.32, 0.74 to 1.75, 0.59 to 1.94 and 1.35 to 3.14 mg kg^{-1}, respectively with a mean value of 8.15, 1.15, 0.98 and 2.18 mg kg^{-1}, respectively.

5.1.3 Microbiological properties

Microbial biomass carbon of soils of the overall area was found, comparatively higher under cultivated conditions (285.4 µg g^{-1}) over buffer conditions (148.7 µg g^{-1}). It varied from 165.2 to 432.5 µg g^{-1} under cultivated conditions in the overall study area. Whereas, under buffer conditions it ranged from 95.6 to 220.3 µg g^{-1}. In overall study area, microbial biomass nitrogen varied from 12.1 to 39.4 µg g^{-1} with a mean value of 25.6 µg g^{-1} under cultivated conditions. While, under buffer conditions it ranged from 9.1 to 17.0 µg g^{-1} with a mean value of 12.9 µg g^{-1}. Soil respiration varied from 95.3 to 254.2 µg CO_2 g^{-1} soil per 24 hrs under vegetable cultivation, whereas in buffer conditions it varied from 90.2 to 154.3 µg CO_2 g^{-1} soil per 24 hrs in the overall studied area. In case of soil respiration, average soil respiration was found comparatively lower (112.6 µg CO_2 g^{-1} soil per 24 hrs) under buffer conditions as compared to cultivated conditions (155.6 µg CO_2 g^{-1} soil per 24 hrs).

5.2 Assessment of soil health

5.2.1 Principal component analysis

Principal component analysis was performed to for minimum data set (MDS) formation, out of 18 variables in PCA, only three PCs had eigen value >1 and explained 66.449 per cent of the variance in the data for soil samples under cultivated and buffer conditions. After selecting the soil quality indicators for MDS, soil quality index was obtained for each site under cultivated and buffer conditions.

5.2.2 Soil quality index and interpretation

In overall study area, the soil quality index under vegetable cultivation varied from 0.579 to 0.982 whereas, in buffer conditions it ranged from 0.492 to 0.586. Overall mean soil quality index was found lower (0.536) under buffer conditions as compared to cultivated conditions (0.738). Among districts, under cultivated conditions Bilaspur district recorded the highest mean soil quality index (0.783), whereas lowest mean soil quality index was observed in district Una (0.701), same trend of mean soil quality index was observed under buffer conditions. Most of the soils of the studied area *i.e.,* 93 per cent of the total area fall under very high soil quality grade according to the classification criteria given by Li *et al*. (2018).

5.3 Yield

In the overall studied area, the yield of cauliflower crop ranged from 155.8 to 228.5 q ha^{-1} with a mean value of 184.4 q ha^{-1}. Among districts, Bilaspur district recorded the highest mean yield of cauliflower crop (190.8 q ha^{-1}) and lowest mean yield of cauliflower crop was observed in district Una (177.1 q ha^{-1}).

5.4 Nutrient concentration in cauliflower leaves

Total nitrogen, phosphorus and potassium content in the cauliflower leaves in the overall studied area varied from 2.07 to 4.15, 0.27 to 0.85 and 2.03 to 3.98 per cent with overall mean values of 3.08, 0.63 and 2.90 per cent, respectively. The content of sulphur, calcium and magnesium in the cauliflower leaves ranged from 0.17 to 0.60, 1.13 to 2.05 and 0.32 to 0.80 per cent with overall mean values of 0.35, 1.49 and 0.61 per cent, respectively.

In overall studied area the contents of iron, zinc, copper and manganese in the cauliflower leaves ranged from 90.78 to 277.65, 22.14 to 70.48, 25.40 to 55.28 and 48.52 to 95.41 ppm with overall mean values of 155.71, 42.97, 35.82 and 71.99 ppm, respectively.

Most of the macro and micronutrients contents of cauliflower leaves of the vegetable growing areas in the studied areas were sufficient while sulphur was deficient in most of the leaf samples of cauliflower.

5.5 Relationship among soil properties and crop productivity

5.5.1 Relationship among soil characteristics

The sand content was found to have highest significant and positive correlation with bulk density and highest negative correlation with silt content. Silt content had a highest significant positive and negative correlation with maximum water holding capacity and sand, respectively. The highest significant positive correlation for the clay content was found with silt content and highest negative correlation with sand content. Bulk density showed non-significant relationships with all the soil properties except for the sand , silt , maximum water holding capacity, organic carbon , exchangeable magnesium , microbial biomass carbon and microbial biomass nitrogen content.

Among chemical properties of the soil, pH was highly significantly correlated with electrical conductivity. Soil electrical conductivity showed a non-significant relationship with all the soil properties except for soil pH, DTPA-extractable manganese, iron and zinc. The organic carbon content was found to have highly significant and positive correlation with microbial biomass carbon content.

Among macronutrients, it was observed from the correlation studies that available nitrogen was highly positively and significantly correlated with the organic carbon content. The available phosphorous showed a non-significant relation with all the soil properties except for pH, DTPA- extractable iron and zinc. Available potassium was highly significant and positively correlated with magnesium content. Available sulphur was also found to be highly significantly and positively correlated with microbial biomass carbon content. A negative and significant correlation between soil pH and micronutrients was observed.

Among microbiological properties, microbial biomass carbon and microbial biomass nitrogen were highly significantly correlated with organic carbon content and negatively correlated with bulk density. Soil respiration had highest significant correlation with organic carbon content followed by microbial biomass carbon.

5.5.2 Relationship of soil properties with yield and nutrient content of leaves

The yield of cauliflower crop was highly significantly correlated with organic carbon content and significantly but negatively correlated with bulk density. The correlation studies shown that the per cent leaf nutrients were highly significantly and positively correlated with their respective value/content in soil.

CONCLUSIONS:

From the present study, it is concluded that

- The pH of soil samples of the studied area were found to be neutral to slightly saline in nature (6.50 to 7.64) and electrical conductivity values were in safe limits (0.154 to 0.287 dS m^{-1}).
- Organic carbon was observed to be high under cultivated conditions in most of the soil samples of the studied area.
- Most of the soil samples of the studied area (82%) were medium in available nitrogen and all the soil samples of studied area were found to be high in available phosphorous.
- Seventy one per cent of soil samples of studied area were high in available potassium and rest twenty nine per cent were medium in available potassium.
- All the soil samples of the studied area were deficient in available sulphur.
- Most of the macro and micronutrients contents of cauliflower leaves of the vegetable growing areas in the studied areas were sufficient.
- Sulphur was deficient in most of the leaf samples of cauliflower.
- Organic carbon showed significant positive correlation with microbial biomass carbon, microbial biomass nitrogen, soil respiration, available sulphur and available nitrogen.
- Negative correlations of all the micronutrients were observed with soil pH.
- Significant positive correlation of leaf nitrogen, phosphorus, potassium, sulphur, calcium, magnesium, iron, copper, zinc and manganese was found with their respective availability in soil.
- Yield of cauliflower crop in the overall area ranged from 155.8 to 228.5 q ha^{-1} with a mean value of 184.4 q ha^{-1}
- Yield of the cauliflower crop was found to be highly significantly correlated with organic carbon content followed by microbial biomass carbon, microbial biomass nitrogen, soil respiration, available sulphur, available nitrogen, exchangeable magnesium, DTPA extractable manganese, maximum water holding capacity and DTPA extractable zinc, iron and copper content.
- The mean soil quality index (SQI) values in district Hamirpur, Una, Bilaspur and in overall studied area were recorded as 0.739, 0.701, 0.783 and 0.738, respectively under cultivated conditions, whereas under buffer conditions, mean soil quality index (SQI) values were observed as 0.537, 0.529, 0.544 and 0.536, respectively.

- Among districts, under cultivated conditions Bilaspur district recorded the highest mean soil quality index (0.783) followed by Hamirpur (0.739), whereas lowest mean soil quality index was observed in district Una (0.701), same trend of mean soil quality index was observed under buffer conditions.
- In the overall studied area, comparatively higher soil quality/health index was observed under cultivated conditions (0.738) as compared to the buffer conditions (0.536).

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ABSTRACT

The investigation entitled "Assessment of soil health under vegetable cultivation in open field conditions of sub-montane and subtropical zone of Himachal Pradesh" was undertaken to assess the effect of vegetable cultivation on soil health and to determine the correlation among soil properties and crop productivity. For this, 45 soil sampling sites were selected randomly and 90 representative soil samples from cultivated and buffer conditions were collected during September, 2020. All the required physical, chemical and microbiological parameters of soil quality were analysed and key indicators were identified using multivariate statistical analysis for computing the soil quality index. The soils of the studied areas varied from sandy loam to loam in texture. Bulk density was found comparatively lower in cultivated conditions as compared to buffer conditions, whereas, maximum water holding capacity showed an opposite trend. The soils were neutral to slightly saline in reaction and EC values of all the soil samples were in safe limits. The overall soil organic carbon content was medium to high in status. Most of the soils were medium in available nitrogen and all the soils of studied area were high in available phosphorous, exchangeable Ca and Mg. Available potassium varied from medium to high and all the soils of the studied area were deficient in available sulphur. Most of the macro and micronutrients contents of cauliflower leaves of the studied areas were sufficient. Sulphur was deficient in most of the leaf samples of cauliflower. Negative correlations of all the micronutrients were observed with soil pH. Yield of the cauliflower crop was found to be highly significantly correlated with organic carbon content. The mean soil quality index (SQI) values in district Hamirpur, Una and Bilaspur were recorded as 0.739, 0.701 and 0.783, respectively under cultivated conditions, whereas under buffer conditions mean soil quality index (SQI) values were recorded as 0.537, 0.529 and 0.544, respectively. In the overall studied area, comparatively higher soil quality/health index was observed under cultivated conditions (0.738) as compared to the buffer conditions (0.536).

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