

**NUTRITIONAL SURVEY OF DRUMSTICK TREE
(*Moringa oleifera*) IN SOLAN DISTRICT OF
HIMACHAL PRADESH**

Thesis

by

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(F-2019-70-M)**

submitted to



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This is to certify that the thesis titled “**Nutritional survey of Drumstick tree (*Moringa oleifera*) in Solan district of Himachal Pradesh**” submitted in partial fulfilment of the requirements for the award of the degree of **MASTER OF SCIENCE (AGRICULTURE)** in the discipline of **Soil Science** to Dr. Yashwant Singh Parmar University of Horticulture and Forestry, (Nauni) Solan (HP) - 173230 India is a bonafide research work carried out by **Mr. Sahil Thakur** son of Shri Sansar Singh Thakur under my supervision and that no part of this thesis has been submitted for any other degree or diploma.

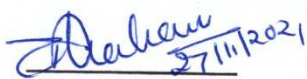
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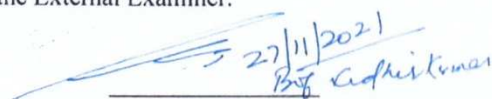
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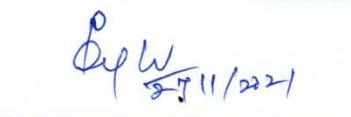

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CONTENTS

CHAPTER	TITLE	PAGE(S)
1	INTRODUCTION	1-3
2	REVIEW OF LITERATURE	4-18
3	MATERIALS AND METHODS	19-28
4	RESULTS AND DISCUSSION	29-49
5	SUMMARY AND CONCLUSION	50-53
	LITERATURE CITED	54-63
	ABSTRACT	64
	BRIEF BIO-DATA	

ABBREVIATIONS USED

%	:	Per cent
Amsl	:	Above mean sea level
B	:	Boron
Ca	:	calcium
CaCO ₃	:	Calcium carbonate
Cm	:	Centimeter
Cmol(p+) Kg^{-1}	:	Centimole proton per kilogram
Cfu	:	Colony forming units
Cu	:	copper
dS m ⁻¹	:	Deci Siemens per meter
DTPA	:	DiethyleneTriaminePenta Acetic Acid
E	:	East
EC	:	Electrical conductivity
<i>et al</i>	:	Co-workers
Etc/etc	:	et cetera
Fe	:	Iron
G	:	Gram
g Kg^{-1}	:	Gram per kilogram
HCL	:	Hydrochloric acid
HNO ₃	:	Nitric acid
HClO ₄	:	Perchloric acid
H.P	:	Himachal Pradesh
Ha	:	Hectare (10,000m ²)
ISSS	:	International society of Soil Science
i.e	:	That is
K	:	Potassium
Kg ha ⁻¹	:	kilogram per hectare
Mg	:	Magnesium
mg Kg^{-1}	:	Miligram per kilogram
Mn	:	Manganese
Mt	:	Metric tons
N	:	Nitrogen
OC	:	Organic carbon
⁰ c	:	Degree celcius
P	:	Phosphorus
pH	:	puissance de Hydrogen
ppm	:	Parts per million
S	:	Sulphur
So ⁴ -S	:	Sulphate sulphur
Viz.	:	videlicet
Zn	:	Zinc

LIST OF TABLES

Table	Title	Page(s)
MATERIAL AND METHODS		
3.1	Locality factors of Study area	20
3.2	Critical limits used for interpretation of pH	27
3.3	Critical limits used for interpretation of electrical conductivity	27
3.4	Critical limits used for available macronutrient of the soil	27
3.5	Critical limits for available micronutrients	27
3.6	Critical limits of nutrients for plant samples	28
RESULTS DISCUSSION		
4.1	Soil texture of Moringa trees at different locations of Solan district	30
4.2	Soil pH, electrical conductivity (EC), organic carbon (OC) of Moringa trees in Solan district	32
4.3	Available nitrogen, phosphorus and potassium contents (kg ha^{-1}) in soil of Moringa trees of Solan district	34
4.4	Exchangeable calcium, magnesium ($\text{cmol (p}^+) \text{ kg}^{-1}$) and sulphate sulphur (kg ha^{-1}) in soil of Moringa trees in Solan district	36
4.5	DTPA-extractable copper, iron, zinc and manganese contents (mg Kg^{-1}) in soil of Moringa trees in Solan district	39
4.6	Total viable microbial count (cfu/g) in various Moringa trees in Solan district	40
4.7	Nutrient indices of surface soils of Moringa trees in Solan district	40
4.8	Nutrient indices of sub- surface soils of Moringa trees in Solan district	41
4.9	Leaf nitrogen, phosphorus and potassium contents (%) of Moringa trees in Solan district	42
4.10	Leaf calcium, magnesium and sulphur contents (%) of Moringa trees in Solan district	43
4.11	Leaf Iron, zinc, copper and manganese contents (ppm) of Moringa trees in Solan district	44
4.12	Chlorophyll content (Chl a and b) and Protein (%) of Moringa trees in Solan district	46
4.13	Relationship (r-values) of soil chemical properties with available nutrient elements of Moringa trees in Solan district	47
4.14	Relationship (r-values) of surface soil characteristics with leaf nutrient contents of <i>Moringa oleifera</i> of Solan district	48
4.15	Relationship (r-values) of sub-surface soil characteristics with leaf nutrient contents of <i>Moringa oleifera</i> of Solan district	49

LIST OF PLATES

Plate	Title	Between Page(s)
1	General view of <i>Moringa oleifera</i> grown in different locations of Solan district	20-21
2	Total viable microbial count in soil of Moringa trees of Solan district	40-41

LIST OF FIGURES

Figure	Title	Page(s)
1	Sampling sites of Solan district	21

Chapter-1

INTRODUCTION

Forests as ecosystem engineers not only have species-specific effects on soil physicochemical properties and soil communities (soil animal communities and soil microbial communities) (Vesterdal *et al.*, 2013; Prescott and Grayston, 2013) but also regulate climate, mineral cycling and prevent soil erosion (Kozłowski, 2002). The last few decades have seen rapid and continuing development of tree plantations in Asia, particularly in Southeast Asia (Sheil *et al.*, 2009; Krisnawati *et al.*, 2011). India constitutes 3287263 km² of total geographical area out of which 697,898 km² is estimated as Forest cover, which constitutes 21.23% of the total geographical area. Forests are the backbone of the Himalayan region's economy and development, especially in Himachal Pradesh, which amounts to 55,673km² of the total geographic area. The state's total forest cover is 15,433 km², accounting for 27.72% of the state's total geographic area and contributing 2.1 percent of the country's total forest cover (FSI, 2020).

Tree species affect soil nutrient mineralization and availability through soil microorganisms, thus affecting soil fertility (Aponte *et al.*, 2013). In tree plantation considerable amount of nutrients are incorporated into the soil through leaf litter fall and its recycling which in turn balance the nutrient reserve of the soil. It is well known that vegetation is an important factor affecting soil physical and chemical properties. Leaves of different tree species have generated species-specific effects on litter layer decomposition and nutrients released into the soil (Morris *et al.*, 2011; Aponte *et al.*, 2013). The amount of nutrient elements present and their distribution in various soil strata are basically related to the growth and development of young plantations. The vegetation reacts with the aerial environment in many ways and often develops specific soil profile for particular tree species (Mandal *et al.*, 1990). Different tree species give rise to different soil's properties even in the same climatic conditions having similar parent material. Moreover the effect of different vegetations to enrich nutrient status depends on various factors such as the leaf chemistry, behavior of nutrient, nature of soil, organic matter accumulation, microbial activity and quantity of nutrient bearing minerals (Bhoumik and Totey, 1990). The chemical properties of soil pertaining to distribution of nutrients in soil strata is an index to evaluate the degree of leaching and conservation potential of essential mineral elements. Moringa species is one of

the world's most useful plants, it is a fast-growing, much more drought-tolerant and multi-purpose tree that it has been described as a 'miracle tree' (Fuglie, 2003; Amaglo, 2006; Yisehak *et al.*, 2011; Ashfaq *et al.*, 2012). It is also known as horseradish or drumstick tree, is a medium-sized tree belonging to the family Moringaceae, it is adapted to a wide range of soil types, but grows best in well-drained loam to clay loam, neutral to slightly acidic soils, but cannot withstand prolonged water logging. Tree species like *Moringa oleifera*, are considered excellent tree among different tree species for improvement of soil having poor soil fertility status and are fairly tolerant to soil moisture deficit, high soil temperature and frost. It grows where temperature ranges from 26 to 40 °C and annual rainfall totals at least 500 mm. It is a fast growing tree and it has great ability to stand in extensive range of environmental conditions.

According to Fuglie (1999), the uses of *Moringa* included, but not limited to alley cropping (biomass production), animal forage (leaves and treated seed cake), biogas (leaves), domestic cleaning agent (crushed leaves), blue dye (wood), fencing (living trees), fertilizer (seed- cake), foliar nutrient (juice expressed from the leaves), green manure (leaves), gum (tree trunks), honey and sugar cane juice-clarifier (powdered seeds), medicine (all plant parts), ornamental plantings, biopesticide (soil incorporation of leaves to prevent seedling damping off), pulp (wood), rope (bark), tannin for tanning hides (bark and gum), water purification (powdered seeds) and *Moringa* seed oil (yield 30–40% by weight). It is a good source of vitamin A, vitamins B and C, essential minerals, and the sulphur-containing amino acids, methionine and cysteine (Bosch, 2004). The composition of the amino acids in the leaf protein is well balanced (Foidl *et al.* 2001). In general, 100 g of *Moringa* leaves contain four times more vitamin A than the same quantity of carrots, four times more calcium than 100 ml of milk, four times more iron than 100 g of spinach, seven times more vitamin C than 100 g of oranges and three times more potassium than 100 g of bananas. The protein quality of drumstick leaves also rivals that of milk and eggs (Fahey, 2005). Therefore, *Moringa* could be considered as a good alternative to be used to help alleviate the micronutrient malnutrition at household as well as national levels.

Tree species like drumstick (*Moringa olerifera* Lam) is considered excellent tree owing to its faster growth habit, tolerance to adverse climate and edaphic factors and assured economic returns. These species can be grown on marginal soils having poor soil fertility

status and are also fairly tolerant to soil moisture deficit, high soil temperature and frost response. It attains its best growth at an altitude of 600 m above sea level but in Himalayas can be found up to 1000 m. It is endemic to Indian subcontinent, Pakistan, Afghanistan, Bangladesh and different localities of African countries (Oliveira *et al.*, 1999). It occurs and widely distributed in tropical and subtropical region and due to its several important purposes, its cultivation is being done all over the world. India is the prime producer of Moringa (Drumstick) with an annual production of 2.2 million tonnes of tender fruits from an area of 43,600 ha leading to the productivity of around 51 tonnes per ha. Among the different states, Andhra Pradesh leads in both area and production (15,665 ha) followed by Tamil Nadu (13042 ha) and Karnataka (10,280 ha). In other states, it occupies an area of 4,613 ha. (APEDA, 2018). It is also found in different regions of Himachal Pradesh like Bilaspur, Hamirpur, Una and Solan district.

Different plantations are the most accurate measures of soil nutrient availability in any given situation. Foliar analysis is based on the climate and the leaf, which is the plant's center of nutrition. Studies on nutrient availability, growth and development of trees are highly influenced by soil characteristics. Physico-chemical characteristics including nutrient status of soil are the major parameter which governs the growth of plants. Biochemical characterization of soil in respect of determining organic nutrients like carbon, nitrogen, phosphorus and their ratios, estimation of humus and enzymatic activities as well as determination of micro flora is of great importance in elucidating the fertility status of soil mineralization, soil organic matter and resultant microbiological and physico-chemical properties.

Therefore, the present study entitled “Nutritional Survey of *Moringa oleifera* in Solan district of Himachal Pradesh” was carried with the following objectives:

Objectives

1. To study the nutritional and fertility status of *Moringa oleifera*
2. To study the relationship between soil properties and leaf nutrient content of *Moringa oleifera*

Chapter-2

REVIEW OF LITERATURE

In the areas of natural distribution, *Moringa* occurs as a component of the mixed broad leaved/conifer forest along forest of sub-Himalayan tracts, often associated with sal and khair forest or nearby crop fields and river side (Gaur, 2001; Singh *et al.*, 2000). In Bhabar area of Kumaon, Uttarakhand rare types of *Moringa* with beautiful pink-white flowers were recorded at an altitude of 1,000–2,000 m (Strachey, 1974). In neighbouring regions in the Nepal Himalaya it occurs as a common forest species (Bhattarai and Baral, 2006). They also found pink flowered population in Panchkula area of the foothills of Himachal Pradesh in the western Himalaya. This species occurs under protected habitats in the tribal dominated tracts of central India (parts of Bihar, Chhattisgarh and Simlipal region of Orissa) evidently exhibiting trends of protection/semi-domestication (Duthie, 1960). *Moringa* is commonly cultivated as perennial in home gardens in South India. In several areas it is also seen to run wild near areas of cultivation in states of Kerala, Rajasthan, etc. (Shetty and Singh, 1987; Murthy and Venu, 2005). Due to high value of fruits and seed production, this species has rapidly spread to many tropical countries of the world in over last century.

Moringa oleifera is a flowering tree plant commonly known as the ‘Drumstick’ or horseradish tree. It belongs to the genus *Moringa*, which has 13 different species. It is a small deciduous tree usually 5–10 m tall but sometimes grow up to 15 m, with a light, feathery canopy. It is native to India but also widely grown in Nigeria, the Pacific Islands, the Caribbean, the Philippines, South Africa, Asia, Florida and Latin America (Fahey, 2019). It has diversity in its name such as “Shiferaw” in Ethiopia and drumstick tree or horseradish tree in India. It is a fast-growing, multi-purpose tree which is highly drought-tolerant and also one of the most useful trees due to its medicinal and nutritional properties in the world. Hence, globally described as a “miracle tree” (Yishehak *et al.*, 2011). *Moringa oleifera* under the multi-storeyed cropping pattern under the shade of this tree is highly effective for number of crops. The tree is less sensitive for price change, hence, it can overrides mono-cropping. Also, the agroforestry with *Moringa oliferia* plays a vital role in soil and water conservation. An evaluation of soil properties under different arid fruit tree covers is an important area of research to understand the impact of fruit trees on soil’s properties. Changes in soil physical

and chemical properties through plantation have been reported by various workers (Singh *et al.*, 2010).

In tree plantation considerable amount of nutrients are incorporated into the soil through leaf litter fall and its recycling make balance in the nutrient reserve of the soil. The amount of nutrient elements present and their distribution in various soil strata are directly related to the growth and development of young plantations. The vegetation reacts with the aerial environment in different ways and there resulted in the development of specific soil profile for particular tree species (Sharma and Gupta, 1989). Different fruit tree species give rise to different soil properties even in the same climatic conditions having similar parent material. Plant roots system also plays an important role in nutrient recycling. Moreover, the effect of different vegetations to enrich nutrient status depends on various factors such as the leaf chemistry, behaviour of nutrient, nature of soil, organic matter accumulation, microbial activity and quantity of nutrient bearing minerals (Gedda, 2003). The chemical properties of soil pertaining to distribution of nutrients in soil strata is an index to evaluate the degree of leaching and conservation potential of essential mineral elements. Literature on various aspects of the present investigation has been reviewed here under the following heads:

- 2.1 Physical, chemical properties and available nutrient content of forest soils**
- 2.2 Biological properties of forest soil**
- 2.3 Nutritional status and chemical composition of forest trees**
- 2.4 Relationship of the available nutrient elements in soil with leaf nutrient composition**

2.1 PHYSICAL, CHEMICAL PROPERTIES AND AVAILABLE NUTRIENT CONTENT OF FOREST SOILS

Bhola (1995) reported the soil enrichment capacity of seven nitrogen-fixing tree species and found that all species significantly improved soil chemical characteristics when compared to an adjacent unplanted region. However, for organic carbon, available nitrogen, available phosphorus, available potassium, available calcium and available magnesium, total enrichment was reported as 15.52-39.52, 8.59-17.98, 15.36 to 39.52 98.91, 2.09-14.0, and 1.93-9.54 percent, respectively.

Patel and Singh (2000) studied the efficiency of ten multifunctional tree species in improving marginal agriculture in Gujarat's semiarid South Saurashtra area, measuring soil

nutrient status beneath the canopy at (0-20cm) and (20-40cm) depths after two years of planting in Junagarh. Under the canopy of *Albizia lebbbeck*, they found the greatest increase in available N, P, O, and K₂O, as well as percent organic matter at 0-20cm soil level, followed by *Cordia dichotoma*. However, no significant changes in soil pH were seen under the canopy of the diverse tree species.

Pandey *et al.* (2000) studied soil physiochemical properties of *Acacia nilotica* trees in traditional agroforestry system in Central India. The present study responds to the effect of three tree canopy positions, such as mid canopy, canopy edge and canopy gap of *Acacia nilotica*. As texture, Organic carbon, Nitrogen, Phosphorus and soil pH in 0-15, 15-30 cm depth of soil in ten conventional agroforestry system are calculated. Result revealed that in 0-15 cm organic carbon, total nitrogen and total phosphorus is high in mid canopy i.e. 1.18, 0.118, 0.106 g whereas soil pH is higher in canopy edge is 6.75. Whereas in 15-30 cm Total nitrogen and phosphorous is high in mid canopy i.e. 0.102 and 0.065 g whereas soil pH is higher in canopy gap which is 7.15 and organic carbon is high in canopy edge is 1.04 g.

Sah *et al.* (2002) studied nutrient status of natural and stable sissoo forest and declining plantation forest of sissoo in Nepal. Samples were collected from two locations, Hetauda (Healthy site) and Tikane (declining site). Result of soil characteristics of *Hetauda sissoo* stand were like, Na:0.47 g, k: 0.72 g, Ca: 237.5 g, Mg: 6.58 g, Mn: 0.60 g, N: 44.8 g, P: 17.8 g. Tikane sissoo stand consequence is Na: 0.40g, K :1.53g, Ca: 122.3g, Mg: 44.3g, Mn:0.13g, N:106.2g, P:22.60 g. The top layer and subsoil of the *Hetauda sissoo* stand were both sandy, while the *Tilkane sissoo* stand was black coloured sandy-loam soil with a lot of clay both in the top and subsoil layers of organic matter. Result revealed that *Hetauda sissoo* stand has high mineral composition of soil as compare to *Tikane sissoo* stand.

Sundaravalli *et al.* (2002) studied various nutrients like (N, P, K, Ca & Mg). In grasses grown under *Albizzia* plantation and in open grazing land in the semi-arid area of Madurai, their absorption, aggregation, transition, and release in both plant sections and soil were studied. The order of nutrient deposition in plant sections and soil were N>K>Ca>Mg>P. Results revealed that both temperate and tropical grasslands have lower nitrogen concentrations below ground than live shoots, according to the findings. This study reveals that, *Albizzia* trees can increase the nutrient content of under storey grasses due to their rapid leaf turnover and decomposition of nutrient-rich compost, resulting in a substantial increase in soil fertility.

Chandra *et al.* (2010) studied the potential of twelve nitrogen-fixing tree species established by the State Forest Research Institute in Jabalpur, Madhya Pradesh, amid degraded oxisols. The results revealed that increasing the water holding capacity, porosity, and organic matter improved the bio-chemical properties of the soil significantly. When comparing unplanted soil to tree plantations of 19-23 years old, soil nitrogen was increased by 39.8 %, phosphorus 42.1 %, potassium 37 % , and calcium 52 %. The formation of humus through organic matter increased soil microbial activity by up to 2.9 times.

Lelon *et al.* (2010) studied chemical properties of soils on gum elementary compositions from *Acacia senegal* variety *kerensis* in Samburu and Marsabit districts. Soil and gum samples were collected for analysis of pH, carbon, nitrogen and phosphorus. The pH of the soil (6.0 - 6.7) differed slightly (p 0.05) from the pH of the gum (4.54 - 4.50). Organic carbon in soil (4.51 and 4.52) as gum (0.15 %) was slightly higher in Merrile. In Logologo, Laisamis, and Sereolipi, the percentages were 0.073, 0.055, and 0.027 % respectively. The nutritious value of the leaf powder, which includes vitamins, basic amino acids, and phytochemicals, makes it a healthy nutrient source for food supplements and has the ability to improve health of human and animals.

Singh *et al.* (2010) studied the impact of Ber (*Ziziphus mauritiana Lamk*), drumstick (*Moringa olerifera Lamk*), karo (*Carissa congesta Wt.*) and khejri (*Prosopis cineraria L. Druce*) on the physical and chemical properties of soil at various depths (0-15, 15-30, 30-40, 45-60 cm) at Central Institute for Arid Horticulture, Bikaner. Result showed that there was slightly decrease in soil pH and no change in EC. Whereas slightly increase in the Organic carbon (0.04 to 0.13%) and Nitrogen content (69 to 100 kg/ha) under vegetation was recorded. They reported that the drumstick had the most significant increase and conservation in soil fertility of the four fruit plantations, led by Ber.

Wang *et al.* (2010) documented the ability of both N-fixing and non-N-fixing tree species for being used to restore degraded land in southern China. The effects of N-fixing and non-N-fixing species on forest regeneration were contrasted in this analysis, which compared soil properties and N transformations in six forest types. The N-fixing forests had 40–50 percent more soil organic matter and 20–50 percent more Total nitrogen than the non-fixing forests. The N-fixing *Acacia auriculiformis* plantation had the highest soil available P. Result revealed that N-fixing plants, particularly *Acacia mangium*, are more effective at re-establishing C and N cycling processes in degraded land in southern China. Furthermore,

Acacia auriculiformis, an N-fixing bacteria, outperformed other species in terms of increasing soil P availability.

Githe *et al.* (2011) studied physico - chemical properties of soils under *Acacia senegal* varieties. Results of this study revealed that there was significant difference among three varieties. In open canopy, soil nutrients were lower than under the canopy due to the effect of litter accumulation. The three varieties showed beneficial effects on soil nutrient status in Natural ecosystem.

Pahla *et al.* (2013) observed the effects of soil types and levels of manures on initial establishment and growth of *Moringa oleifera*. For this experiment four types of soils i.e. sandy, sandy loam, clay loam and clay and four levels of cattle manure were used. Results showed that application of decomposed cattle manure in acidic granitic sandy soil increase the production of tree (plant height, no. of branches, basal stem diameter, roots and shoots length). A mixture of clay loam and 40% manure was also reported best for *M. oleifera* growth.

Bale *et al.* (2015) studied the comparison between physicochemical properties (density, specific gravity, refractive index, pH, viscosity peroxide value, and iodine value saponification value) of *Moringa oleifera* (Nigeria), *Moringa oleifera* (Kenya), *Moringa oleifera* (India). In this study, oil yield was found to be low while *Moringa* seeds still remains a good source of oil rich in oleic acid that could be converted in to biofuel.

Matali and Matali (2015) studied soil physiochemical properties of *Acacia mangium* plantation and health forest. In each soil core pH., Gravimetric water content, organic matter, organic layer depth, texture and major nutrients concentration were fixed. As the result *Acacia* plantation soils had remarkably higher total N concentration than the high frequency soils and *A. mangium* trees have ability to change physical properties of soils to improve their growth.

Omar and Mohammad (2015) studied physical-chemical properties of soil in three different plantations under *Acacia senegal* in Maifari, Jigawa state and Nigeria. As a result, three sites in Nigeria's semi-arid zone were chosen for evaluation, reflecting three plantation ages of 7, 27, and 37 years old. Soil samples were taken under tree canopies and compared to soil samples taken in open areas. The results showed that the three ages had substantial

variations in soil physicochemical properties (P 0.05 and P 0.01). Regardless of the canopy form, soil nutrients were higher under the canopies than in the open canopies. Primarily as a result of litter accumulation and increased herbage production in agricultural rangelands was led improved soil nutrient status will boost animal production.

Solana *et al.* (2015) studied the chemical composition and nutritional value of dried *Moringa oleifera* leaf powder collected from two region in Mexico and found that predominant mineral elements in leaf powder were Ca (2016.5-2620.5 mg/100g) K (1817-1845 mg/100g). As chemical composition values confirmed that *M. oleifera* leaves are an excellent food source, as in direct use for human nutrition and proper balanced diet for animal nutrition.

Wang *et al.* (2015) studied the behavior of soil physico-chemical properties, soil enzymes and soil microbial species in four different regions, each separated by *Mimosa pudica* invasiveness in the Yifengpo in South China. Four sites in the research area were chosen and graded based on *M. pudica* coverage. Result revealed that the soil organic matter, pH, total N, P, and K, available N contents were higher in the heavily invaded area than those in the newly invaded area. Total N, total P, available N, P, K, and soil microbial biomass C, N, and P were all affected by *M. pudica* invasion. When opposed to the native sites, the occupied sites, soil enzyme processes and microbial communities were also substantially different then natural habitats. The invasive mechanism can be aided by improvements in soil properties.

Hu *et al.* (2016) studied changes that came in physiochemical and microbiological properties of soils with elevation gradients in two forest soils i.e. *Betula platyphylla* and *Picea crassifolia*. Biolog- ECO plates and phosphorus fatty acid analysis were used to measure microbial activity of soils and biomass. Results revealed that soils at higher altitude were characterized by lower pH and higher organic matter and nutrients levels than lower altitude. SOM showed negative effects on microbial biomass of soil but no effects on soil microbial activity and soil pH was negatively correlated with soil microbial activity and biomass.

Adebayo *et al.* (2017) studied the effects of sources, rates of NPK (15:15:15), compost on soil properties and productivity of *Moringa* at National Horticulture Research Institute, Ibadan, Nigeria and found that growth values for NPK and compost treatment were

higher than control. Post planting soil analysis showed that pots with organic and inorganic fertilizers have higher contents of nitrogen, phosphorus, calcium, sodium, manganese, iron and zinc.

Leon *et al.* (2017) studied the soil parameters of *Moringa oleifera*. For this study soil samples were collected and designated as A, B, and C. For each soil sample, parameters like pH, cation exchange capacity, electrical conductivity, the content of organic matter, the levels of K, P and NH₄ were determined. Results showed that values of OM, NH₄, P, K, tree age, total phenolics, gallic acid, total carotenoids were found higher in soil sample A. Soil B represented higher values of EC, pH, sand, antiradical activity and organic matter, as well as minor value of CEC, silts, clay etc. Soil sample C has minor value of tree age, phenolics, OM, P, K, EC and highest value of silt, clay.

Mabapa *et al.* (2017) studied the physiochemical properties of *Moringa oleifera* at two different experimental sites i.e. Syferkull (university of Limpopo experimental farm) and Ofcolaco (Itemeleng Ba Makhutjwa experimental farm). As in a randomised complete block configuration, four different planting densities (435,000, 300,000, 200,000, and 100,000 plants/ha) were arranged, and experimental samples were repeated four times. Result revealed that Nutrient level of soil under Syferkull experimental farm shows better result as compared to ofcolaco experimental farm.

Zhou *et al.* (2017) studied changes in microbial community structure associated with different legumes species which were recorded as higher than those associated with grass species. Results of this study reveals that legumes improves quality of fungi greatly than grasses and legumes and grasses affect soil pH, dissolved organic carbon, total nitrogen and phosphorus content.

Verma *et al.* (2017) studied the ameliorative effect on soil physico-chemical properties of sodic soils and found that soil bulk density was remarkably reduced from starting 1.8 to 1.32 Mg/m³ whereas soil porosity, moisture equivalent and water holding capacity were increased. Overall improvement was observed in soil physico-chemical properties. The soil pH, exchangeable sodium percent and electrical conductivity were decreased under *Acacia nilotica* plantation.

Chauhan *et al.* (2018) studied physical, chemical and biological status under four multipurpose tree plantation (*Acacia catechu*, *Dalbergia sissoo*, *Melia aazadrach* and

Terminalia arjuna) and evaluation was done after ten years of growth on riverain soils which revealed that nutritional level under canopy of *Terminalia arjuna* as higher than other three species. The physical and chemical parameters showed refinement in all four species. An enhanced enzymatic activity was noticed under the soil of different species, as a result of which, ameliorative potential of soil through plantation under degraded soils was observed.

Sadeq *et al.* (2020) studied the physicochemical properties of soils and annual understory species in the deserted rangelands of Bahrain. The soil properties of the understory and uncanopied adjacent areas of *Prosopis juliflora* were calculated. Result revealed that when comparing the understory of trees to the uncanopied adjacent areas, soil bulk density at the 0–5 cm soil depth was slightly higher in the understory of trees. In all soil depths, no variations in pH, EC, K, Na, or Ca were observed between the understory and the uncanopied regions. The understory of trees had slightly higher levels of N, P, Mg, and organic matter than the uncanopied neighbouring regions.

2.2 BIOLOGICAL PROPERTIES OF FOREST SOIL

In the rhizosphere, Lazarovits and Nowak (1997) reported population of bacteria in the range of 95×10^5 cfu/g soil. From the root area or rhizosphere of vegetable crops, a significant number of microorganisms capable of solubilizing insoluble phosphates have been identified. P-solubilizers have a higher population in the rhizosphere (20-40%) than in non-rhizosphere soil (10-15%) as compared to the overall population (Kapoor *et al.*, 1989). Shishido *et al.* (1999) found that the average endophytic bacterial population in spruce roots was 150 cfu/g root.

According to Selvi *et al.* (2004), the bacterial population in soil varied from 22 to 76×10^5 cfu/g soil, followed by actinomycetes (4 to 8×10^3 cfu/g soil) population under a cropping system that included finger millet, maize, and cowpea fodder grown successively on the same piece of land.

Chakunda *et al.* (2019) used composite soil sample of *Moringa oleifera* (Lam.) and *Annona muricata* (L.) of 0-35 cm depth for studying microbial diversity. Different species of fungi isolated and identified from the rhizosphere of the forest Arboretrum were *Rhodotorulasp* (F.C. Harrison) *Aspergillus niger* (van Tieghem), *Microsporum audouinii* (Gruby), *Sporotrichum pruinosum* (J.C. Gilman and E.V. Abbot), *Aspergillus versicolor* (Budapest and Treaty). However, the bacteria isolated from *Moringa oleifera* and *Annona*

muricata were *Bacillus* sp (Ehrenberg) and *Micrococcus* sp (Schroeter and Cohn). Generally, five fungi and two bacteria organisms were isolated, identified and classified into their different phylum, class and genera and cell morphology/microscopic characteristics.

By choosing three typical watersheds, Kaushal *et al.* (2005) investigated microbial diversity in distinct geoclimatic zones of Himachal Pradesh. In the Moolbari watershed in the middle altitudinal range, the highest microbial activity (3.50 mg CO₂ C/g soil) was seen under grassland. The highest microbial biomass (137.28 g/g soil) was found in soils used for agriculture (cereal) land use in the Me GaD watershed, which is located at a higher altitude zone.

2.3 NUTRITIONAL STATUS AND CHEMICAL COMPOSITION OF FOREST TREES

Makkar *et al.* (1997) studied the nutritional potential of different morphological parts of a tree. As crude protein percent of leaves, twigs and stems was calculated which is 64, 79 and 67%. As a result *Moringa oleifera* leaves served as a good source of supplementary protein for animal feeds.

Pandit and Prajapati (2003) analysed trace elements like Fe, Cu, Zn and Mn of three different species of *Acacia* like *A. nilotica*, *A. senegal* and *A. Leucophloea* in the reserve forest area near Bhavnagar. Result revealed that higher gathering of Fe than other elements Fe (8.02 to 83.42 µg/ml) was pursued by Cu (1.17 to 6.70 µg/ml) and Zn (0.98 to 32.68 µg/ml). During the study time, neither molybdenum nor boron were found in the plants mentioned above. Cu and Zn concentrations were found to be extremely important in all species.

Aslam *et al.* (2005) studied the mineral composition of leaves and pods of *Moringa oleifera* from different agro climatic zones of Punjab. Samples were wet digested and analyzed by Atomic absorption spectrophotometer and flame photometer. The minerals like K, Ca, Mg, Na and micronutrients Fe, Cu, Zn, Mn were finally analysed and have attained positive result from all different agro-climatic zones of Punjab which is very feasible companion of dietary minerals for animals.

Yang *et al.* (2006) studied nutritional and antioxidant values of four different species of Moringaceae family from different countries like India, Arabia, Kenya and Madagascar. Minerals like Iron, Calcium, Magnesium, zinc, Copper and other Fiber, Sugar, Proteins and

Vitamins are calculated. Result revealed that all species contain adequate amount of minerals. As Protein content was found superior in *Moringa oleifera* as compare to other three species which would lead to better nutrition and health

Anjorin *et al.* (2010) studied the mineral composition of the lamina, petiole and seed pod of *Moringa oleifera* leaves from two different regions, Sheda and Kuje in Abuja, Nigeria. As Ca, Mg, Fe and Cu of Sheda were comparatively higher than Kuje. Result revealed that there were variations in macro and trace minerals in *Moringa* leaves and seeds from both locations.

Charles *et al.* (2011) studied the chemical composition and nutritional values of *Moringa oleifera* leaves collected from three different sector of Ouagadougou. The percentage of proteins, moisture, fat, mineral composition, carbohydrates of the leaves were slightly higher in dry matter as compare to cool matter. As a result adequate composition and a remarkable variability between nutrient content of different sectors were recorded.

Moyo *et al.* (2011) studied the nutritional value of *Moringa* leaves of the South African ecotype. Van soest methods was used to calculate nutritional values of *Moringa* leaves. Calcium had the highest value of 3.65% and phosphorus had the least value of 0.30 % among the macro-elements. The highest value among the micro-minerals was Fe with 490 mg/kg and Copper had the least value of 8.25 mg/kg. Result of this study showed that values of amino acids, minerals and vitamin profiles shows a good nutritional stability.

Yameogo *et al.* (2011) studied chemical composition and nutritional values of *Moringa oleifera* leaves from three different locations in Ouagadougou. The Comparison is shown between cool and dry matter. Result of analyzed samples from various methods revealed that the dry matter contains high proteins, moisture, fat and carbohydrates, respectively 27.2, 5.9, 17.1 and 38.6% whereas mineral composition of dry matter also contain high Calcium, Magnesium, Potassium, Iron, Zinc and Phosphorus, respectively 2098.1, 406.0, 1922.0, 28.3, 5.4 and 351.1. As this plant can be valorised for a balanced nutrition of populations.

Oluduro (2012) studied nutritional and antimicrobial properties of *Moringa oleifera* leaves in south western Nigeria. As mineral analysis showed that calcium, magnesium and iron attain good amount of mineral content and Antibacterial activity was resolute by

measurement of zone of inhibition around each paper disc. As results revealed that leaves can be good diets to supplement human daily needs nutrients.

Ogbe and Affiku (2012) studied mineral and anti-nutrient composition of *Moringa oleifera* leaves from Lafia in Nigeria. Amount of Na, Fe, K, Ca, Mn, Zn and P were adequate as magnesium and copper were the least. The level of anti-nutrients were low which reveals that leaves from this plant are good feed supplement and has great medicinal values for good health and growth performance.

Mensah *et al.* (2012) looked into the phytochemical, dietary, and antibacterial properties of *Moringa oleifera* dried leaf powder from Edo Central Province, Nigeria. Result revealed that presence of carbohydrates (29.08 %), ascorbic acid (140 mg/100 g); fibre (2.1 %), protein (6.88 %) as well as iron (70 mg/100 g), calcium (1530 mg/100 g)), vitamin C (17.8 mg/100 g) potassium (255 mg/100 g), magnesium (250 mg/100 g) and vitamin A (19.9 mg/100g). It shows that the dry leaf powder is a good source of phytochemicals/secondary metabolites and nutrients but not antimicrobials.

Asante *et al.* (2013) conducted an experiment in two agro-ecological zones of Ghana named Guinea Savanna and semi deciduous forest. Leaf samples were collected from 3 district of each ecological zones. The calcium value of semi-deciduous forest was higher than comparison to Guinea savanna, as no significant difference was observed in values of potassium and Iron. Results revealed that agro ecological zones had no vital effect on level of better nutrients in *Moringa oleifera* leaves.

Ameri *et al.* (2014) studied the phytochemical composition and nutritional value of *Moringa peregrina* and *Moringa oleifera* leaf and fruit extracts. The powdered plant samples were analysed separately for phytochemical constituents such as total phenol content, micro and macro components using appropriate methods. As compared to *Moringa peregrina*, the ash content, overall phenol content, protein, macro elements (Ca, K, Mg, Na, P), and micro elements (Cu, Co, Fe, Mn, Zn) were all higher in *Moringa oleifera*. Result revealed that *Moringa oleifera* leaves are great source of nutrition to animals and plants.

Shaika *et al.* (2014) studied the phytochemical composition and nutritive contents of *Moringa oleifera* and *Moringa peregrine* from leaves and fruits. The study revealed that ash content, protein, macro and micro nutrients were all higher in *Moringa oleifera* as compared

to *Moringa peregrine*. As these leaves are good source for medicinal agents, human and plant growth and development.

Offor *et al.* (2014) studied the nutritional and metal composition of dried *Moringa oleifera* leaves from Oshiri, Onicha in Nigeria. Results of this study revealed that Moringa dried leaves contain good amount of crude protein, high amount of iron content which is good source of additional protein for man and livestock.

Verma and Nigam (2014) studied nutritive values and chemical composition of *Moringa oleifera* leaves from Jabalpur city of Madhya Pradesh, India. As Protein, Carbohydrates and minerals like zinc, iron, calcium, potassium, sodium and magnesium are calculated by analysing data respectively 33, 7 and 23% , respectively. Minerals as 15.96, 4.11, 141.42, 700.83, 16.93 and 15.26. As potassium and magnesium was found highest overall locations. Therefore, adequate composition and a remarkable variability between nutrient content of different locations were recorded.

Chinwe *et al.* (2015) studied the physio and phyto-chemical properties of *Moringa oleifera* leaves from the matured tree in an orchard within the plantation of Faculty of Agricultural Sciences. The study revealed the following nutrients, proteins (24.31 %), carbohydrate (55.97 %), ashes (11.50 %), crude fiber (10.28 %), total fat (9.22 %), moisture (6.12 %). caloric value (404.10 Kcal 100 g) and monounsaturated fatty acids in leaves of Moringa suggesting their use for drug formulation.

Gopalakrishnan *et al.* (2016) studied the nutritive importance for medicinal purposes of *Moringa oleifera*. Samples were collected from four different locations of Hyderabad. Result revealed the Protein%, Carbohydrate, Fibre, Calcium, Phosphorus, Magnesium, Copper, Iron and Sulphur as 27.1, 38.2, 19.2, 2003, 368, 204, 1324, 0.57, 28.2 and 870g, respectively. As *Moringa oleifera* has great nutritive values therefore it is very efficient as good diet supplement for proper growth and development of human and animals.

Lopez *et al.* (2017) studied chemical composition, minerals and antioxidant capacity in two variants of *Moringa oleifera* leaves grown in Sinaloa, Mexico. The protein and iron content was found high in both variants. Result showed that *Moringa oleifera* leaves are important source of proteins and minerals.

Williams *et al.* (2017) studied the effectiveness of NPK, green manure of *Tithonia diversifolia* and *Chromolaena odorata* leaves on the growth of *Moringa oleifera*. Data were collected for growth parameters of *Moringa oleifera* seedlings. Result reveals that *Tithonia diversifolia* had higher plant growth parameter as compare to other treatments on soil. As green manure, compost material will help poor resource farmer to produce liveable and productive crop yield.

Abbas *et al.* (2018) reported protein, macro and micro nutrients, vitamins and crude fibre of *Moringa oleifera* leaves under semi-arid conditions of Sudan. Various methods like Soxlet extractor, Kjeldahl method and atomic absorption spectrophotometer were used to calculate these parameters. It revealed that carbohydrates, proteins and dietary fibre result into 9.1, 8.1, 2.1 g. Minerals like Calcium, Iron, Magnesium, Manganese, Phosphorus, Potassium, Sodium and Zinc result into 99.1, 1.3, 35.1, 0.119, 70.8, 471, 70 and 0.85 mg. All the parts of *Moringa Oleifera* have good amount of minerals and vitamins for making them suitable for both human and animals.

Raokhande (2021) studied nutritional and therapeutic values of *Moringa oleifera* leaves. Various methods were performed to calculate the minerals and vitamins present in it. Results revealed that % of RDA provided by 30g of *Moringa oleifera* powder shows Calcium 60 %. Magnesium 37 %, Iron 84 %, Copper 19 %, Potassium 11.35 %, Phosphorus 9 % and protein 12.8 %. Vitamin A, Vitamin B and Vitamin C are 163 %, 52.8 % and 8.6 %. Result of this study showed that values of minerals and vitamin profiles shows a good nutritional stability.

2.3 RELATIONSHIP OF THE AVAILABLE NUTRIENT ELEMENTS IN SOIL WITH LEAF NUTRIENT COMPOSITION

Sharma and Bhandari (1992) discovered a statistically significant link between Cu and Fe content in leaves and soils, but Mn content in leaves and soils was only statistically significant for surface soils. They also discovered a statistically significant relationship between soil and leaf K.

Sharma (1994) discovered that available N and Mn had a positive and very significant connection with leaf content in both surface and sub-surface soils in another research. P and K, on the other hand, had a positive but statistically insignificant association with their respective leaf content.

Hosur and Dasog (1995) studied the nutrient status of soil and leaves of tree plantations (*Tectona grandis*, *Dalbergia sissoo* and *Acacia catechu*) on the properties of Dharwad's red loam soil (inceptisol). Result revealed that soil pH was found higher in Teak plantation and Organic carbon was high in Shisham plantation. The return of nitrogen, calcium, and potassium among different nutrients was higher in all three organisms. Phosphorus and magnesium yields were much lower. Both the physical and chemical properties of the soil are enhanced under all three plantations, according to the report. *D. sissoo* produced the greatest change in soil properties of the three plantation.

Awasthi *et al.* (1998) revealed that available N, P, K, Ca, and Mg had a substantial and positive relationship with leaf nutrient content. The soil N, on the other side, had a strong and negative correlation with leaf P, K, and Ca, and a positive correlation with Mg. According to Awasthi *et al.* (1999), all available soil nutrient components exhibited a significant positive relationship with their respective leaf nutrient concentration.

Geesing *et al.* (2000) studied physico-chemical properties of soil and leaves of *Prosopis glandulosa* on nitrogen and carbon development. Soil parameter like soil organic carbon, N, P, K, Soil pH were measured. Result revealed that , soil N ($p=0.004$), soil C ($p=0.0001$), soil C/N ($p=0.01$), soil P ($p=0.0005$), leaf N ($p=0.04$), leaf P ($p=0.01$), and wood P ($p=0.02$). As the soil N was significantly correlated with leaf N , the soil P was significantly correlated with leaf P.

Mugunga *et al.* (2013) studied soil properties and plant diversity of *Acacia sieberiana* in Songa Pastures, Rwanda. Plants were identified under and away from tree crowns, and soil properties were determined. Nitrogen, phosphorus, and potassium were measured in the soil, Grass and *Acacia sieberiana* leaves. Soil characteristics was determined by various methods and Plant diversity was determined using Simpson's diversity index. Result revealed that Soil organic carbon, Cation exchange capacity, Calcium, Nitrogen, and pH, as well as plant diversity, were all higher in tree-canopy soils than in open areas. As compared to grasses, tree leaves were slightly higher in N and lower in P and K.

Dania *et al.* (2014) studied comparative effects of different fertilizer sources on the growth and nutrient content of Moringa in greenhouse trial. It revealed that phosphorus and potassium concentration have a 0.07 percent positive correlation, and phosphorus and sodium

have a 0.01 percent positive correlation in *Moringa oleifera* greenhouse trial. The findings revealed that as phosphorus levels rise, potassium and sodium levels rise as well. It was also reported that there was a 0.01 percent positive connection between nitrogen and iron, calcium and iron, and nitrogen and copper, as well as a 0.01 percent positive correlation between magnesium and zinc. The results reveal that as the amount of nitrogen and calcium in the soil grew, so did the amount of iron in the soil.

Kumssa *et al.* (2017) studied the concentration of Copper in *Moringa oleifera* leaves was significantly ($p < 0.05$) and positively associated with total soil Cu and Fe concentrations. Similarly, leaf Fe concentration also showed a statistically significant ($p < 0.05$) and positive correlation with soil Fe, Se and Zn. Selenium concentration in *Moringa* leaves showed a stronger significant ($p < 0.05$) positive correlation with phosphate extractable (Se-P) soil Se. The Ca and Zn concentration in *Moringa* leaves showed no statistically significant ($p \geq 0.05$) correlation with any of the reported soil properties.

Chapter-3

MATERIALS AND METHODS

The present investigation entitled “Nutritional Survey of (Drumstick tree) *Moringa oleifera* in Solan District of Himachal Pradesh. The experimentation and its scientific validation depend upon the methodology adopted. The importance of soil quality attributes varies among different soils in various Agro-ecological conditions and therefore, site specific information is needed for evaluation of soil fertility. This chapter presents the analytical tools and methods employed to achieve the specific objectives under different sections and sub-sections under the following heads;

- 3.1 General description of the study area**
- 3.2 Sampling sites**
- 3.3 Collection and preparation of soil and leaf samples**
- 3.4 Soil and plant analysis methods**
- 3.5 Interpretation of data**
- 3.6 Statistical analysis**

3.1 GENERAL DESCRIPTION OF STUDY AREA

3.1.1 General description

Solan district is located between 30°50'30" to 30°50'00" N latitude and 77°08' 30" and 77°11'30" E longitude (Survey of India Toposheet No.53F/1). The elevation of district ranges from 300 to 3000 m amsl. The present investigation was carried out in the Solan Forest Division under Nahan Forest circle of Himachal Pradesh.

The Solan Forest division lies between longitudes 76°56' and 77°12' East and latitudes 30°46' and 31° 10' North. The geographical area of the division is 721.30 Sq. Kms. It is bounded on the North by the Shimla Forest Division, by the Rajgarh Forest Division in the East, on the West by Kunihar Forest Division and on the South by boundary of Haryana State. The whole area of the division is a compact block except for Rugra block of Subathu Range, access to which can be had either by crossing Kunihar or via Ghanahatti near Shimla. It can be appropriate to mention here that there are no Reserved or Protected forests falling

under this block. The entire track is hilly starting from outer Shiwalik to Middle Himalayas and covering the forests, which lies between the altitudes of 500 meters to the 2500 meters.

3.1.2 Climate

The climate of the area is transitional between sub-temperate to sub humid with maximum temperature rising to 37.8° C during summer. The mean annual temperature is 19.8°C. May and June are the hottest months, whereas, December and January are the coldest. The annual rain fall ranges between 1150 mm of which 75 per cent is received during mid June to mid September.

Due to variation in altitude in this Division, the temperature also varies considerably. Minimum temperature goes down below 0°C in high reaches during winter season and maximum temperature exceeds 40°C in lower reaches during the summer season.

3.1.3 Edaphic characteristics

The parent material consist of sand stone, conglomerate, boulders, dolomite and calcareous. The soil type is inceptisols and typic entrochrepts with loam to clay loam texture. The description of site is given in table no.3.1

Table 3.1 Locality factors of Study area

Latitude	30°46' to 31° 10' N
Longitude	76°56' to 77°12' E
Altitude	1250 m amsl
Climate type	Sub temperate and sub humid
Texture	Loam to clay loam
Mean annual rainfall	1150 mm
Mean annual temperature	19.8°C
Soil pH	6.48

3.2 Sampling sites

The study was conducted in 4 Block (Solan, Kunihar, Dharampur, Nalagarh) of Solan district of Himachal Pradesh. From each Block 3 locations

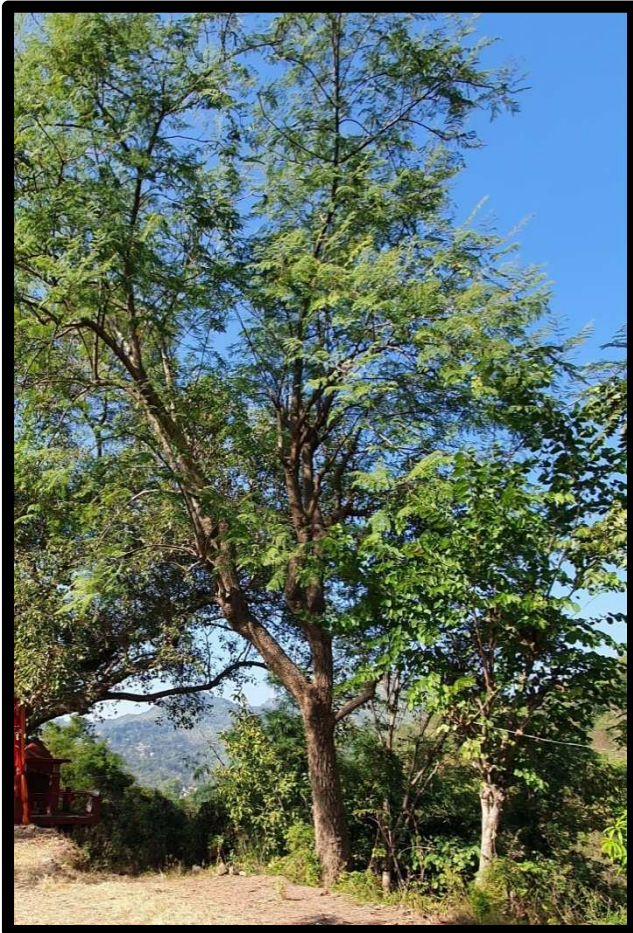


Plate 1: General view of *Moringa oleifera* grown in different locations of Solan district

were selected and from each location 5 matured trees of *Moringa oleifera* were selected to evaluate physical-chemical and microbiological properties of soil.

3.2.1 Sampling data and locations

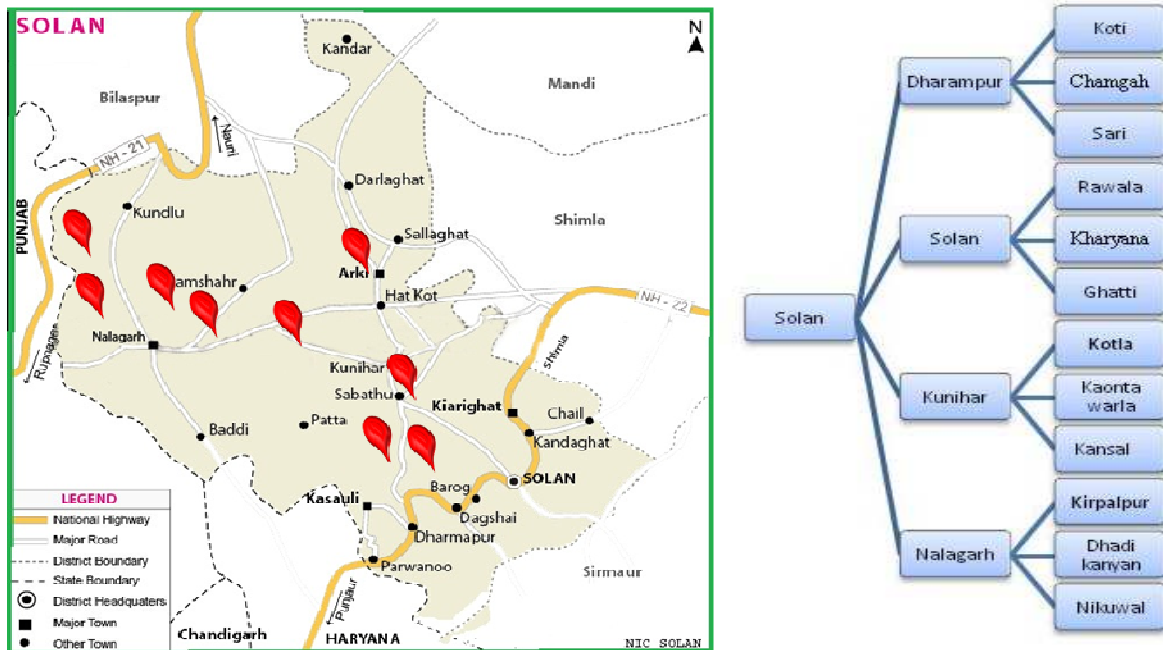


Fig 1: Sampling sites of Solan district

3.3. COLLECTION AND PREPARATION OF SOIL AND LEAF SAMPLES

3.3.1 SOIL SAMPLING

Soil samples were collected from the basins of trees from two depths i.e., 0-15 (cm) and 15-30 (cm) during the months of Nov-December. The soil samples were air dried and grinded with help of wooden pestle and mortar and passed through a 2mm sieve. The processed samples were stored in plastic container with appropriate labels for further analysis.

3.3.2 LEAF SAMPLING

Representative leaf samples comprising of 60-100 leaves were taken from the same trees which were used for collection of soil samples. Fully expanded leaves were drawn from selected trees from each location. The leaf samples were washed with ordinary water and then with 0.1N HCl followed by washing with distilled water. They were dried in an oven at

60±5°C for 72 hours. The dried samples were ground in stainless steel grinder for proper mixing of plant material and stored in paper bags for subsequent analysis (Chapman, 1964).

3.4 SOIL AND PLANT ANALYSIS METHODS

The soil and plant samples were further analyzed for different parameter like texture, pH, electrical conductivity (EC), organic carbon (OC), available macro and micro-nutrients (N, P, K Ca, Mg, S, Fe, Cu, Zn, Mn, B, Mo) using standard methods given below.

3.4.1 Soil texture

Soil texture was determined by relative distribution of sand, silt, and clay in the sample by Hydrometer method (Bouyoucos, 1962).

3.4.2 Soil pH

The soil pH was measured with the help of a digital pH meter by making 1:2 soil water suspensions (Jackson, 1973).

3.4.3 Electrical conductivity

The electrical conductivity was measured with the help of electrical conductivity meter by making 1:2 soil water suspensions and keeping it overnight (Jackson, 1973).

3.4.4 Organic carbon

The organic carbon of the samples was determined by wet digestion method (Walkley and Black, 1934).

3.4.5 Available macro and micro-nutrients

Surface and sub-surface soil samples were analyzed for the following nutrient elements.

3.4.5.1 Available Nitrogen

The available nitrogen was determined by alkaline permanganate method of Subbiah and Asija (1956).

3.4.5.2 Available Phosphorous

The available phosphorous was estimated by extraction with 0.5M sodium bicarbonate at pH 8.5 as described by Olsen *et al.* (1954).

3.4.5.3 Available Potassium

The available potassium was estimated by the method of Merwin and Peech (1951), where soil was extracted with neutral normal ammonium acetate and determined by flame photometer.

3.4.5.4 Exchangeable Ca and Mg

Available Ca and Mg in the ammonium acetate extract were determined by atomic adsorption spectrophotometer (Sarma *et al.*, 1987).

3.4.5.5 SO_4^{2-} Sulphate Sulphur

SO_4^{2-} Sulphate Sulphur was extracted by Morgan's reagent and determined by turbidity method by (Chesnin and Yien 1950).

3.4.5.6 DTPA extractable micronutrients

Available Fe, Mn, Cu and Zn contents in soil were extracted by using DTPA-extractant at pH 7.3 (Lindsay and Norvell, 1978) and determined by Atomic Absorption Spectrophotometer.

3.4.6 Microbiological parameters

3.4.6.1 Media preparation

Three types of media were used for the isolation of (Bacteria, fungi and actinomycetes) as total viable microbial count.

The compositions of the media used are given below:

Nutrient agar (NA)

Beef extract	:	3.0 g
Peptone	:	5.0 g
NaCl	:	5.0 g
Agar Agar	:	20.0 g
Distilled Water	:	1000.0 g

Potato dextrose agar media (PDA)

Potatoes	:	250.0 g
Dextrose	:	20.0 g

Agar- Agar	:	20.0 g
Distilled water	:	1000 ml

Kenknight's media

K ₂ HPO ₄	:	1.0 g
NaNO ₃	:	0.1 g
KCL	:	0.1 g
MgSO ₄ .7H ₂ O	:	0.1 g
Glucose	:	1.0 g
Agar-Agar	:	20.0 g
Distilled water	:	1000 ml

3.4.6.2 Total viable soil microbial count (bacteria, fungi and actinomycetes)

The serial dilution and plating techniques suggested by Rao (1997) were employed for isolation and identification of viable bacteria, actinomycetes and fungal count. Three specific growth media were prepared for desired micro flora. The autoclaved and cooled (45°C) medium was poured into sterile plates and allowed to solidify. One gram of sieved (02 mm) soil was added to 9 ml sterile water blank and shaken for 15-20 minutes. Serial dilutions of 10¹, 10², 10³, 10⁴, 10⁵, 10⁶ and 10⁷ were prepared and 0.1 ml of aliquots of various dilutions were added, over cooled and solidified medium in Petri plates, using the pour plate method. The plates were rotated for uniform distribution of bacterial cells and fungal spores in the aliquot under the media and allowed to solidify. After the media was solidified, the plates were inverted and incubated at 28° C for 3-4 days. The appearance of colonies on the surface of the medium in the plates were observed. Population count of bacteria, fungi and actinomycetes was noted using dilution plate technique by employing nutrient agar (NA), potato dextrose agar medium (PDA) and Kenknight's media, respectively. The population was expressed as colony forming units (cfu g¹ soil).

3.4.7 Soil nutrient indices

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

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

Where,

NL	=	number of samples falling in low category of nutrient status
NM	=	number of samples falling in medium category of nutrient status
NH	=	number of samples falling in high category of nutrient status
NT	=	total number of samples analyzed for a given nutrient

3.4.8 Plant analysis

Leaf samples were digested in a diacid of HCl: HClO₄ (4:1) for P, K, Ca, Mg S, Fe, Cu, Zn, Mn and Mo estimation and final volume was made to 100 ml (Jackson, 1973).

3.4.8.1 Nitrogen

The total leaf nitrogen was determined by micro-kjeldhal's method as described by Jackson (1973).

3.4.8.2 Phosphorous and Potassium

Phosphorus in the digest was determined by vandomolybdate yellow color method (Jackson, 1973) and potassium was determined by Flame photometer. (Jackson, 1967).

3.4.8.3 Calcium and Magnesium

Leaf calcium and magnesium were determined by Flame photometer and Atomic Absorption Spectrophotometer, respectively.

3.4.8.4 Sulphur

Leaf Sulphur was estimated by turbidimetric method (Chesnin and Yien, 1950).

3.4.8.5 Micronutrients

Leaf Zn, Cu, Fe and Mn were determined on Atomic Absorption Spectrophotometer (Vogel, 1978).

3.4.8.6 Protein Content

The oven dried samples of *Moringa* leaves were analyzed for total nitrogen following kjeldahl method (Jackson, 1973). Nitrogen content determined as per the procedure was multiplied by 6.25 to get the protein content in leaves.

3.4.9 Leaf chlorophyll content

Five fully expanded and mature leaves were collected from selected trees of every locations during morning hours, immediately placed in ice box and brought to the laboratory and kept in refrigerator till further analysis. The leaves from each sample were then chopped into fine pieces under subdued light and 100 mg chopped leaf samples were placed in vials containing 7 ml of dimethyl sulphoxide. The contents of the vials were incubated at 65°C for half an hour and then the extract was transferred to graduated test tube. The final volume was made to 10 ml with Dimethyl sulphoxide (Hiscox and Israelstam, 1979).

Estimation

The optical density (OD) values of the extract were recorded in Spectrophotometer (Thermo-Scientific Spectronic 20 D⁺) at 645 and 663 nm wavelength against a dimethyl sulphoxide blank. The total chlorophyll content was calculated by using the following formula:

$$\text{Total chlorophyll} = \frac{20.2 A_{645} + 8.02 A_{663}}{A \times 1000 \times W} \times V$$

Where,

V	=	Volume of the extract made
A	=	Length of the light path in cell (usually 1 cm)
W	=	Weight of the sample (g)
A ₆₄₅	=	Absorbance at 645 nm
A ₆₆₃	=	Absorbance at 663 nm

The results thus obtained were expressed as mg/g of fresh weight.

3.5 INTERPRETATION OF DATA

Results of soil analysis were interpreted using the critical limits given in Table 3.1 and Table 3.2 and plant analysis results were interpreted using Table 3.3.

Table 3.2 Critical limits used for interpretation of pH

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

Table 3.3 Critical limits used for interpretation of electrical conductivity

EC (dS m ⁻¹)	Soil category	Reference
Below 0.8	Normal-suitable for all crops	Raina <i>et al.</i> (2007)
0.8-1.6	Critical for salt-sensitive crops	
1.6-2.5	Critical for salt-tolerant crops	
Above 2.5	Injurious to all crops	

Table 3.4 Critical limits used for available macronutrient of the soil

Sr. No.	Nutrient elements	Soil fertility class			References
		Low	Medium	High	
1	Organic carbon (g/kg)	< 0.5	0.5-1.0	> 1.5	Bhandari and Tripathi (1979)
2	Nitrogen (kg/ha)	< 280.0	280.0-560.0	> 560.0	Anonymous (2015)
3	Phosphorous (kg/ha)	< 10.0	10.0-25.00	> 25.00	
4	Potassium (kg/ha)	< 118.0	118-260.0	>260.0	
Secondary micronutrients					
		Deficient	Sufficient		
1	Available Ca [cmol(p ⁺)/kg ⁻¹]	<1.5	1.5	Anonymous (2015)	
2	Available Mg[cmol(p ⁺)/kg ⁻¹]	<1.0	1.0		
3	Sulphate S (kg/ ha ⁻¹)	<22.5	22.5		

Table 3.5 Critical limits for available micronutrients

Micronutrients (mg/kg)	Availability			References
	Low	Medium	High	
Zn	<1.0	1.0-3.0	>3.0	Lindsay and Norvell, (1978)
Cu	<0.3	0.3-0.8	>0.8	
Fe	<4.0	4.0-6.0	>6.0	
Mn	<1.2	1.2-3.5	>3.5	

Table 3.6 Critical limits of nutrients for plant samples

Sr No. A. Macronutrients (per cent)	Nutrient Element	Concentration			References
		Low	Medium	High	
1	N	1.50-1.80	1.80-2.40	>2.50	Plant analysis laboratory of Ohio State University, USA
2	P	0.15-0.18	0.18-0.28	>0.30	
3	K	1.00-1.20	1.30-1.80	>1.90	
4	Ca	1.00-1.20	1.30-1.70	>1.80	
5	Mg	0.20-0.24	0.24-0.36	>0.37	
6	S	<0.1	>0.1	-	
B. Micronutrients (ppm)					
7	Zn	15.0-20.0	20.0-50.0	>50	
8	Cu	5.0-10.0	10.0-20.0	>20	
9	Fe	30.0-35.0	35.0-150.0	>150	
10	Mn	25.0-30.0	31.0-150.0	>150	

3.6 STATISTICAL ANALYSIS

The descriptive statistics viz., range, mean, standard deviation and coefficient of variation were derived for each soil (0 to 15 and 15-30 cm) and leaf parameter. Simple correlations were computed to establish the relationship of soil physicochemical properties with plant nutrient composition using standard statistical procedure as per the methods outlined by Panse and Sukhatme (2000).

Chapter-4

RESULTS AND DISCUSSION

The results emerging from the present investigations entitled “**Nutritional survey of Drumstick tree (*Moringa oleifera*) in Solan district of Himachal Pradesh**” has been described under the following broad heads:

4.1 Soil properties

4.1.1 Physical and chemical properties of the soils

4.1.2 Available Macronutrient status of soil

4.1.3 Available Micronutrient status of soil

4.1.4 Total Viable Microbial Count (cfu/g) (Bacteria, fungi and actinomycetes)

4.2 Nutrient indices of soil

4.3 Leaf nutrient status

4.3.1 Leaf Macronutrient content

4.3.2 Leaf Micronutrient content

4.3.3 Chlorophyll content (Chl ‘a’ and ‘b’) and Protein (%)

4.4 Relationship of soil properties with available soil nutrient contents

4.5 Relationships of soil physical and chemical properties with plant nutrient contents.

4.1 SOIL PROPERTIES

The data presented in tables revealed variations in soil properties associated with *Moringa oleifera* trees grown under natural conditions in different locations of district Solan. The study was conducted in 4 Block (Solan, Kunihar, Dharampur, Nalagarh) of Solan district of Himachal Pradesh. From each Block 3 locations were randomly selected and from each location 5 matured trees of *Moringa oleifera* were selected to evaluate soil physico-chemical and microbiological properties of soil.

4.1.1 Physical and chemical properties of the soils

4.1.1.1 Soil Texture

The data presented in table revealed variation in soil texture among samples collected from different *Moringa* trees grown at different locations of Solan district. Sand content in surface layer (0-15 cm) ranged from 51.20-66.60 with mean value of 60.21, whereas in sub-

surface layer (15-30 cm) it ranged from 44.10-65.34 with the mean value of 56.28. The C.V was 6.96 and 11.88 for Sand content in both surface and sub-surface layers and showed that it varies spatially. Silt content in surface layer (0-15 cm) ranged from 10.5-27.6 with mean value of 21.73, whereas it ranged from 13.5-27.9 in sub- surface layer (15-30 cm) with a mean value of 21.38. The C.V calculated was 21.39 and 16.24 for silt content in both surface and sub-surface layers and it varies spatially. Clay content in surface layer (0-15 cm) ranged from 10.9-22.9 with mean value of 17.66, whereas in sub- surface layer (15-30 cm) the range was between 13.31-36.1 with the mean value of 22.71. The C.V was 19.84 and 29.37 for Clay content in both surface and sub-surface layers showed spatial variation.

With increasing soil depth, the proportion of sand decreased and the percentage of silt and clay increased, indicating a translocation of finer soil fractions to lower depths, according to the cumulative range data.

Table 4.1 Soil texture of Moringa trees at different locations of Solan district

Blocks	Locations	Sand (%)		Silt (%)		Clay (%)		Textural Class	
		Soil Depth (cm)							
		0-15	15-30	0-15	15-30	0-15	15-30	0-15	15-30
Dharampur	L ₁	55.70	54.00	25.10	25.20	18.30	20.60	Sl	Scl
	L ₂	63.10	45.00	25.00	18.90	11.90	36.10	Sl	Scl
	L ₃	62.00	44.10	27.10	19.90	10.90	36.00	Sl	Cl
Solan	L ₁	66.60	63.50	10.50	13.50	22.90	23.10	Scl	Scl
	L ₂	59.60	58.50	21.40	21.90	17.90	19.20	Sl	Scl
	L ₃	66.00	60.00	18.00	20.00	16.00	20.00	Sl	Scl
Kunihar	L ₁	51.20	50.40	27.60	27.90	20.20	21.90	Scl	Scl
	L ₂	58.90	58.10	22.10	22.50	20.50	21.30	Scl	Scl
	L ₃	59.70	59.10	19.10	21.70	19.40	20.80	Sl	Scl
Nalagarh	L ₁	61.20	65.34	22.83	21.35	15.97	13.31	Sl	Sl
	L ₂	59.70	59.30	22.20	22.60	18.10	19.50	Sl	Sl
	L ₃	58.80	58.00	19.80	21.10	19.90	20.70	Sl	Scl
Range		51.20-66.60	44.10-65.34	10.5-27.6	13.5-27.9	10.9-22.9	13.31-36.1		
Mean		60.21	56.28	21.73	21.38	17.66	22.71		
SD		4.19	6.69	4.65	3.47	3.51	6.67		
CV(%)		6.96	11.88	21.39	16.24	19.84	29.37		

*sl= Sandy loam scl= Sandy clay loam

The cumulative data range revealed that as soil depth increases, the percentage of sand was decreased and the percentage of silt and clay was increased, showing that finer soil components get translocated to lower depths. Gupta and Verma (1992) had reported a greater clay content in the subsurface strata, which was ascribed due to clay downward translocation under increased rainfall.

The results recorded in the present findings are according to the Kumari *et al.* (2018), Rao *et al.* (1997) and kumar and Paliyal (2018). They have reported greater clay content in the subsurface strata of the districts of Solan, Sirmour, Hamirpur, Una and Kangra.

In general, the soil texture in the surface and sub-surface soils varied from sandy loam to the sandy clay loam. A predominant of sandy clay loam soil texture was observed in all selected locations.

4.1.1.2. Soil pH

From the perusal of data presented in Table 4.2, the soil pH in the surface 0-15 cm layer ranged from 6.83 to 7.84 with the mean value of 7.34. The respective ranges were 7.63 to 8.91 in the subsurface 15-30 cm strata, with mean value of 8.24, respectively (Table 4.2). The soil pH varies spatially at the surface and sub-surface depths, with a CV of 4.27 per cent and 4.57 per cent, respectively.

The lowest pH 6.83 was reported in the surface soils of Nalagarh block, whereas highest pH of 8.91 was in sub-surface soils of Kunihar block of district Solan.

The most significant chemical characteristic of soil is soil reaction, which controls nutrient availability and microbial activity. Broadly it is evident that the pH range from 6.5 to 7.5 is ideal for the availability of the majority of nutritional elements as well as microbial activity. Data presented in table 4.2 revealed that the soil pH was almost neutral at different locations and the values varied from 6.83 to 8.91. The pH of the soil rises with depth, which might be due to reduced organic matter content and weathering soil conditions at deeper depths. It might be possible because the higher horizon receives the most leaching from rainfall and dissolved carbonic and organic acids, which remove metal cations and replace them with hydrogen ions, but the lower horizon does not (Adebayo *et al.* 2017, Sharma and Dogra, 2011).

4.1.1.3 Electrical conductivity (EC)

The electrical conductivity in the surface 0-15 cm layer ranged from 0.33 to 0.55 dSm⁻¹ with the mean value of 0.47 dSm⁻¹. In the sub-surface 15 to 30 cm layers the electrical conductivity was found to decrease and it varied from 0.27 to 0.49 dSm⁻¹ with mean value of 0.40 dSm⁻¹ (Table 4.2). The CV of 13.56 % and 16.10 % for EC indicates that it varied spatially in the surface and sub-surface depths of soil.

In comparison to the deep layer, the surface layer had higher EC values. Average EC values in the range from 0.370-3.80 dSm⁻¹ have also been reported in the soils of Rajgarh and Solan Divisions (Verma, 2003).

4.1.1.4 Organic carbon (OC)

The amount of litter produced and the rate of decomposition are the factors that influence the effectiveness of specific species with increasing organic carbon. Soil organic carbon is a possible determinant of soil fertility because it enhances soil physical, chemical and biological characteristics, all of which influence soil production under certain climatic circumstances. The perusal of the data depicted in Table 4.2 shows that the organic carbon content in the surface 0-15 cm layer ranged from 2.03 to 2.64 per cent with the mean value of 2.32 whereas, in the sub-surface layers it ranged from 1.97 to 2.51 per cent with the mean value of 2.19 per cent. The CV for Organic carbon was 9.20 % and 8.85 % in the surface and sub-surface layer of soil.

Table 4.2 Soil pH, electrical conductivity (EC), organic carbon (OC) of Moringa trees in Solan district

Blocks	Locations	Soil pH (1:2)		EC (dS m ⁻¹)		OC (%)	
		Soil Depth (cm)					
		0-15	15-30	0-15	15-30	0-15	15-30
Dharampur	L ₁	7.26	8.07	0.53	0.39	2.52	2.35
	L ₂	7.55	8.13	0.49	0.41	2.34	2.21
	L ₃	7.09	7.97	0.55	0.46	2.64	2.43
Solan	L ₁	7.63	8.27	0.41	0.31	2.09	2.03
	L ₂	6.89	7.63	0.43	0.39	2.11	2.07
	L ₃	7.46	8.71	0.33	0.27	2.18	2.11
Kunihar	L ₁	7.59	8.23	0.53	0.49	2.53	2.47
	L ₂	7.52	8.91	0.51	0.48	2.47	2.01
	L ₃	7.84	8.78	0.47	0.39	2.57	2.51
Nalagarh	L ₁	6.83	8.03	0.42	0.38	2.03	1.97
	L ₂	7.26	7.98	0.44	0.37	2.16	2.06
	L ₃	7.11	8.19	0.49	0.41	2.25	2.11
Range		6.83-7.84	7.63-8.91	0.33-0.55	0.27-0.49	2.03-2.64	1.97-2.51
Mean		7.34	8.24	0.47	0.40	2.32	2.19
SD		0.31	0.38	0.06	0.06	0.21	0.19
CV(%)		4.27	4.57	13.56	16.10	9.20	8.85

Although the organic carbon in all the analysed soil samples of trees were rated high but it decreases with increasing depth, which may be ascribed due to the litter fall on surface soil.

Hazra and Tripathi (1986), Hussain *et al.* (1987) and Gupta and Tripathi (1989) have also reported decrease in organic carbon content with increasing depth.

4.1. MACRO NUTRIENT STATUS OF SOIL

4.1.2.1 Available nitrogen

From the perusal of data presented in Table 4.3 reveals that the available nitrogen in the surface 0 to 15 cm layers ranged from 310.54 - 458.04 kg ha⁻¹ with the mean value of 402.53 kg ha⁻¹. In the sub-surface 15-30 cm layers values ranged from 319.11-414.40 kg ha⁻¹ with the mean value of 376.11 kg ha⁻¹. The CV of 9.63 % and 8.28 % for available N indicates that, it varied spatially in the soil surface and sub- surface depths, respectively.

The fertility classifications revealed that the N content of the soil of Moringa trees of Solan district is in medium range, and that the available N decreases as soil depth increases. Maximum nitrogen content was recorded in soil samples in Kunihar block and minimum was in Nalagarh block.

As predicted, nitrogen-fixing plants prove more effective than non-fixing trees in increasing available nitrogen content. Khajuria (2005) and Verma (2003) have also reported that most of parent soils of mid hill region of Himachal with low to medium in their available N status.

4.1.2.2 Available phosphorus

The data regarding the status of available phosphorus is presented in Table 4.4. The available phosphorus content at surface depth ranged from 33.6-49.19 kg ha⁻¹, with a mean value of 42.16 kg ha⁻¹, whereas it ranged from 29.56-46.73 kg ha⁻¹, with a mean value of 38.26 kg ha⁻¹ in sub-surface depth. The CV of 10.93 % and 11.65 % for available P indicates that, it varied spatially in the surface and sub- surface depths, respectively

The fertility classification in Table 4.7 reveals that the P concentration in the soil of Moringa-growing areas of Solan district is high, and the available P decreases as soil depth increases (Table 4.3).

The high P value in surface soils was attributable to the large amount of organic carbon, litter generated, and a faster rate of decomposition, all of which increased the P availability in the soil. Due to its limited mobility at deeper levels, P concentration decreases as soil depth increases.

Similar findings for available phosphorus under tree canopies have been reported by Palled *et al.* (1987), Sharma and Gupta (1989) and Bhola (1995).

4.1.2.3 Available potassium

The available potassium content was enumerated which showed that the available potassium at surface depth ranged from 366.69-403.45 kg ha⁻¹, with a mean value of 385.87 kg ha⁻¹, Whereas it ranged from 358.87-392.68 kg ha⁻¹, with a mean value of 378.17 kg ha⁻¹ in sub-surface depth. The CV of 11.60 % and 11.09 % for available K indicates that, it varied spatially in the surface and sub- surface depths, respectively

Table 4.3 Available nitrogen, phosphorus and potassium contents (kg ha⁻¹) in soil of Moringa trees of Solan district

Blocks	Locations	Nitrogen		Phosphorus		Potassium	
		Soil Depth (cm)					
		0-15	15-30	0-15	15-30	0-15	15-30
Dharampur	L ₁	419.60	414.40	49.19	46.73	392.61	385.27
	L ₂	416.37	410.07	47.61	41.34	388.69	382.62
	L ₃	393.41	391.67	44.53	39.28	391.63	381.69
Solan	L ₁	400.76	373.24	39.20	35.84	381.26	378.69
	L ₂	387.23	327.63	33.60	29.56	386.24	375.21
	L ₃	392.14	371.35	35.84	33.60	380.94	372.24
Kunihar	L ₁	450.82	388.01	42.07	38.62	399.21	390.63
	L ₂	458.04	388.03	46.68	42.62	403.45	392.68
	L ₃	434.60	412.01	40.11	35.14	395.43	389.54
Nalagarh	L ₁	383.86	361.72	42.50	38.50	368.62	361.68
	L ₂	310.54	356.08	43.30	40.20	366.69	358.87
	L ₃	383.01	319.11	41.23	37.71	375.63	368.89
Range		310.54-458.04	319.11-414.40	33.6-49.19	29.56-46.73	366.69-403.45	358.87-392.68
Mean		402.53	376.11	42.16	38.26	385.87	378.17
SD		38.78	31.15	4.61	4.46	11.60	11.09
CV(%)		9.63	8.28	10.93	11.65	3.01	2.93

The fertility classification in Table 4.7 reveals that the K concentration in the Moringa-growing areas of Solan district is high, and the available K decreases as a soil depth increases (Table 4.3). Dhyani *et al.* (1990) reported that available potassium was high in soil under tree spp. like *Bauhinia purpurea* and *Leuceana leucocephella* as compared to area which is devoid of trees hence justify the present results.

4.1.2.4 Exchangeable calcium

A critical perusal of data remunerated in Table 4.4 showed that the Exchangeable Calcium levels in the 0 to 15 cm layer of the surface varied from 5.96-7.40 [cmol (p+) Kg⁻¹], with a mean value of 6.60 [cmol (p+) Kg⁻¹]. It varied from 5.86-7.12 [cmol (p+) kg⁻¹] in the subsurface 15 to 30 cm strata, with a mean value of 6.49 [cmol (p+) kg⁻¹] (Table 4.3). Exchangeable Ca had a C.V of 7.76 per cent and 7.14 per cent, indicating that it varied spatially in the surface and sub-surface depths. The amount of Exchangeable Calcium in the soil was recorded to deplete as the depth of the soil increased. The soils in Solan district Moringa trees were rich in Exchangeable calcium, according to the categorization shown in Table 4.7 and 4.8. The increased Ca levels in soils might be attributed to the high calcium carbonate concentration and neutral pH.

Broadly the general status of Ca in Solan district soils is high. This might be due to the nature of the parent material in hill soils. Since the Calcium was found as dominant cation in soils of Pine forest of Himachal Pradesh (Sahu and Bala 1995), so as the case of Ca in soil of naturally grown Moringa trees. Similar trend of distribution was reported by Hosur *et al.* (1995) and Biswas *et al.* (2017).

4.1.2.5 Exchangeable magnesium

The data depicted in Table 4.4 revealed that the Exchangeable magnesium in the 0 to 15 cm layer of the surface varied from 2.59 to 3.09 [cmol (p+) kg⁻¹], with a mean value of 2.87 [cmol (p+) kg⁻¹]. The value for the subsurface varied from 2.55 to 3.05 [cmol (p+) kg⁻¹], with a mean value of 2.81 [cmol (p+) kg⁻¹] (Table 4.4). The Exchangeable Mg had a C.V of 6.20 per cent and 6.22 per cent, respectively, indicating spatially variability in the surface and sub-surface depths. In the Moringa-growing soils of Solan district, the overall status of Exchangeable magnesium was registered high. As soil depth increases, the concentration of Exchangeable magnesium was dropped.

The similar findings have been reported by Hosur *et al.*(1995), Biswas *et al.* (2017) and Kumari (2015) where the Mg content in the soil was registered in the range from 2.13 to 3.69.

4.1.2.6 Sulphate sulphur (SO₄⁻² -S)

The data presented in Table 4.4 shows that the sulphate sulphur concentration in surface soils varied from 21.65 to 29.90 Kg ha⁻¹, with a mean value of 26.00 Kg ha⁻¹. For the sub-surface layer, the value ranged from 21.71 to 27.87 [cmol (p⁺) Kg⁻¹] with the mean value 24.68 [cmol (p⁺) Kg⁻¹], respectively (Table 4.4). The SO₄^{-S} had a CV of 10.25 per cent and 9.06 per cent, indicating a spatial variation in the surface and sub-surface depths.

In the Moringa -growing soils of Solan district, the overall status of Sulphate sulphur was registered to be in medium range i.e. 8 per cent in surface and 17 per cent in sub-surface area and 92 percent of the surface area and 83 percent of the subsurface area were found to be in the high range.

Table 4.4 Exchangeable calcium, magnesium (cmol (p⁺) kg⁻¹) and sulphate sulphur (kg ha⁻¹) in soil of Moringa trees of Solan district

Blocks	Locations	Calcium		Magnesium		Sulphur	
		Soil Depth (cm)					
		0-15	15-30	0-15	15-30	0-15	15-30
Dharampur	L ₁	7.09	6.93	3.03	2.99	23.33	21.71
	L ₂	7.14	7.01	3.09	3.05	29.45	27.87
	L ₃	7.40	7.12	3.06	3.02	27.7	24.5
Solan	L ₁	6.18	6.07	2.67	2.62	26.87	25.13
	L ₂	5.96	5.86	2.63	2.58	29.9	27.6
	L ₃	6.68	6.61	2.59	2.55	27.54	26.87
Kunihar	L ₁	7.18	7.03	2.96	2.87	24.98	23.45
	L ₂	6.65	6.57	3.02	2.92	21.65	21.86
	L ₃	6.24	6.19	2.99	2.91	23.54	23.11
Nalagarh	L ₁	6.00	5.97	2.85	2.79	28.34	27.32
	L ₂	6.06	5.99	2.8	2.74	23.65	23.12
	L ₃	6.65	6.55	2.76	2.69	25.07	23.65
Range		5.96-7.40	5.86-7.12	2.59-3.09	2.55-3.05	21.65-29.9	21.71-27.87
Mean		6.60	6.49	2.87	2.81	26.00	24.68
SD		0.51	0.46	0.18	0.17	2.67	2.24
CV (%)		7.76	7.14	6.20	6.22	10.25	9.06

The sulphur concentration recorded in the soil of Moringa growing selected areas of Solan district are justified by Wadia's (1966) finding, who attributed it to the nature of the parent material, which is gypsiferous and ferruginous limestone. The results are also in line with the findings of Sharma (1994), Annepu *et al.* (2017) and Biswas (2017) where sufficient amount of sulphur in the soils of Himachal Pradesh were documented.

4.1.3 Micronutrient status of soil

4.1.3.1 DTPA extractable iron (Fe)

The data presented in Table 4.5 reported that the DTPA extractable iron in the surface (0-15cm) soils ranged from 5.92 to 15.04 mg Kg⁻¹ with the mean value of 10.10 ppm. It varied from 4.13 to 14.25 ppm in sub-surface soils, with a mean value of 10.10 and 9.46 ppm, respectively (Table 4.5). DTPA Fe had a CV of 42.18 per cent and 34.51 per cent, respectively, indicating that it changed spatially in the surface and sub-surface depths. The available iron content of surface soils was much larger than that of sub-surface soils, owing to the higher range of organic matter concentration in surface soils.

Apart from the existence of ferruginous limestone parent materials comprising haematite and limonite minerals, the increased Fe concentration might be due to acidic to near neutral soil response (Wadia, 1966). Similar results have been reported by Annepu *et al.* (2017) and Vaidya *et al.* (2017)

4.1.3.2 DTPA extractable copper (Cu)

The data presented in Table 4.5 reported that, the DTPA extractable copper concentrations ranged from 1.28 to 4.14 mg kg⁻¹ in the surface depth and 1.05 to 3.44 mg kg⁻¹ in the sub-surface depth with mean value of 2.60 and 2.21 mg kg⁻¹ (Table 4.5). DTPA Cu had a C.V of 35.17 per cent and 31.72 per cent, indicating that it changed spatially in the surface and sub-surface depths. The DTPA extractable copper concentration dropped as depth increased, although all of the blocks followed the same pattern as the surface layer.

In the Moringa –growing selected regions of Solan district, the general status of DTPA extractable copper was recorded to be high in range (Table 4.7).

Similar results were also reported by Annepu *et al.* (2017) and Vaidya *et al.* (2017) where the range of DTPA extractable copper was at higher range.

4.1.3.3 DTPA extractable zinc (Zn)

The data depicted in Table 4.5 revealed that the DTPA extractable zinc content in the surface and sub-surface soil ranged from 2.24 to 4.11 mg kg⁻¹ and 2.05 to 4.05 mg kg⁻¹ with the mean value of 3.32 mg kg⁻¹ and 3.14 mg kg⁻¹, respectively. The C.V for DTPA Zn was 18.07 per cent and 20.71 per cent, indicating that it varied spatially in surface and sub-surface depths. With increasing soil depth, the amount of DTPA extractable Zn decreased.

A perusal of the data revealed in table 4.7 indicated that 33 per cent was found medium and 77 per cent at high range in surface and sub-surface soils. The overall condition of the Solan district's Moringa trees is high in range.

The results are in line with the findings of Annepu *et al.* (2017) where a medium concentration of micronutrients were reported in Himachal Pradesh soils, with available Zn ranging from 0.29 to 5.07 mg/kg⁻¹.

Zn concentrations often decreased with depth, which matched the distribution pattern of organic carbon in profile.

4.1.3.4 DTPA extractable manganese (Mn)

The DTPA extractable manganese in the 0 to 15 cm surface layers varied from 17.13 to 31.32 mg kg⁻¹, with a mean value of 23.57 mg kg⁻¹. Its value in the subsurface layers ranged from 16.17 to 29.61 mg kg⁻¹, with a mean value of 21.62 mg kg⁻¹, respectively (Table 4.5). DTPA Mn had a C.V of 37.37 per cent and 38.79 per cent, indicating that it changed spatially in the surface and subsurface depths. Its content was found to reduced with the increasing in soil depth.

The values in the table 4.7 revealed that Mn content in Moringa trees were high in Solan district.

According to Mahajan (2001), soils in the Mandi area of Himachal Pradesh were rich in DTPA-Mn, whereas Singh (2001) found that 5% of Indian soils were low in available Mn. Similar readings were found by Adebayo *et al.* (2017)

Table 4.5 DTPA-extractable copper, iron, zinc and manganese contents (mg Kg⁻¹) in soil of Moringa trees of Solan district

Blocks	Locations	Iron		Copper		Zinc		Manganese	
		Soil Depth (cm)						0-15	15-30
		0-15	15-30	0-15	15-30	0-15	15-30		
Dharampur	L ₁	14.79	13.29	3.76	2.26	2.92	2.6	24.84	21.51
	L ₂	15.04	14.25	3.20	2.84	3.54	3.22	21.23	19.36
	L ₃	14.87	13.98	2.58	2.42	3.24	3.02	29.51	27.96
Solan	L ₁	12.22	11.95	1.98	1.71	4.02	3.95	20.03	17.11
	L ₂	11.74	9.54	1.70	1.58	3.96	3.91	21.61	18.93
	L ₃	9.32	8.12	1.28	1.05	4.11	4.05	17.13	16.17
Kunihar	L ₁	7.38	6.12	4.14	3.44	3.48	3.34	27.64	24.32
	L ₂	10.01	9.12	3.78	3.25	3.58	3.41	29.51	27.12
	L ₃	11.74	9.54	2.18	2.04	3.38	3.23	31.32	29.61
Nalagarh	L ₁	7.38	6.52	2.02	1.72	2.42	2.31	17.97	16.87
	L ₂	6.31	4.13	2.13	1.91	2.24	2.05	18.63	17.65
	L ₃	5.92	5.73	2.41	2.27	2.94	2.62	23.42	22.78
Range		5.92-15.04	4.13-14.25	1.28-4.14	1.05-3.44	2.24-4.11	2.05-4.05	17.13-31.32	16.17-29.61
Mean		10.10	9.46	2.60	2.21	3.32	3.14	23.57	21.62
SD		4.26	3.26	0.91	0.70	0.60	0.65	4.94	4.71
CV(%)		42.18	34.51	35.17	31.72	18.07	20.71	20.94	21.77

4.1.5 Total Viable Microbial Count (Bacteria, fungi and actinomycetes)

The data depicted in Table 4.6 revealed that the soil viable microbial count ranged for bacteria ($83.77-98.74 \times 10^5 \text{ g}^{-1}$ soil) with mean value of $91.50 \times 10^5 \text{ g}^{-1}$ soil. The CV for bacterial count is $5.78 \times 10^5 \text{ g}^{-1}$ soils (Table 4.6). For fungal count the value ranged from ($81.64-95.13 \times 10^2 \text{ g}^{-1}$ soil) with mean value of $87.57 \times 10^2 \text{ g}^{-1}$ soil. The CV for fungal count is $5.35 \times 10^2 \text{ g}^{-1}$ soils. For actinomycetes count the value ranged from ($8.12-10.53 \times 10^3 \text{ g}^{-1}$ soil) with mean value of $9.47 \times 10^3 \text{ g}^{-1}$ soil. The CV for actinomycetes count is $6.87 \times 10^3 \text{ g}^{-1}$ soils (Table 4.6).

High organic matter present in soil serves as additional food for these microbes. In addition, leaf litter improves the conditions by keeping the soil temperature sustains. Rich organic matter and ambient temperature sustains the proliferation of microflora in soil. The results are in line with Rajput (2016) who had reported similar range of microbial count in the soil of mid hills of Himachal Pradesh.

Table 4.6 Total viable microbial count (cfu/g) in various soils of Moringa trees of Solan district

Blocks	Locations	Soil microbial count		
		Bacteria ⁵ · ⁻¹ (10 g soil)	Fungi ² · ⁻¹ (10 g soil)	Actinomycetes ³ · ⁻¹ (10 g soil)
Dharampur	L ₁	95.46	89.76	10.16
	L ₂	93.17	88.24	9.79
	L ₃	96.43	89.39	10.53
Solan	L ₁	88.44	87.93	8.88
	L ₂	90.71	84.71	9.13
	L ₃	86.17	82.37	8.12
Kunihar	L ₁	97.85	93.61	9.58
	L ₂	95.23	92.34	8.99
	L ₃	98.74	95.13	9.91
Nalagarh	L ₁	85.81	82.18	9.58
	L ₂	83.77	81.64	9.14
	L ₃	86.23	83.51	9.79
Range		83.77-98.74	81.64-95.13	8.12-10.53
Mean		91.50	87.57	9.47
SD		5.29	4.68	0.65
CV(%)		5.78	5.35	6.87

4.2 NUTRIENT INDICES OF SOIL

A perusal of data in table 4.7 of the surface layers reveals that 100.00 and 33.00 per cent samples fall under medium category with respect to N and Zn. Although 92.00, 77.00 and rest 100.00 per cent samples fall under high category with respect to S, Zn and P, K, Ca, Mg, Fe, Cu and Mn.

Table 4.7 Nutrient indices of surface soils of Moringa trees in Solan district

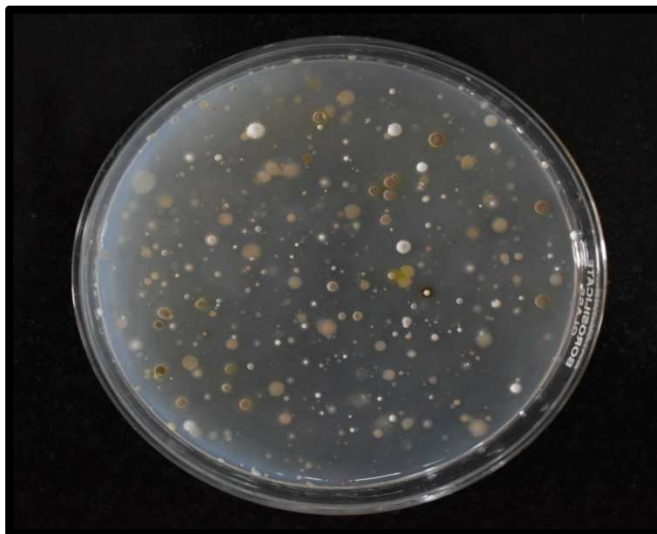
Nutrients	Percentage of samples rating			Nutrient Index	Nutrient Status
	Low	Medium	High		
Surface Soil Depth (0-15 cm)					
N	-	100	-	2.00	Medium
P	-	-	100	3.00	High
K	-	-	100	3.00	High
Ca	-	-	100	3.00	High
Mg	-	-	100	3.00	High
S	-	8	92	2.91	High
Fe	-	-	100	3.00	High
Cu	-	-	100	3.00	High
Zn	-	33	77	2.60	High
Mn	-	-	100	3.00	High



Bacterial count (10^5 g⁻¹ soils)



Fungal count (10^2 g⁻¹ soils)



Actinomycetes count (10^3 g⁻¹ soils)

Plate 2: Total viable microbial count in soils of *Moringa* trees of Solan district

Nutrient indices indicate that soils of the district, as regards the nutrient status are medium in available nitrogen (2.00), whereas in available phosphorus (3.00), available potassium (3.00), available calcium (3.00), available magnesium (3.00), sulphate sulphur (2.91), DTPA iron (3.00), DTPA extractable Cu (3.00), DTPA extractable zinc (2.60) and DTPA extractable Mn (3.00) soils are high in nutrient status.

Table 4.8. Nutrient indices of sub- surface soils of Moringa trees in Solan district

Nutrients	Percentage of samples rating			Nutrient Index	Nutrient Status
	Low	Medium	High		
Surface Soil Depth (0-15 cm)					
N	-	100	-	2.00	Medium
P	-	-	100	3.00	High
K	-	-	100	3.00	High
Ca	-	-	100	3.00	High
Mg	-	-	100	3.00	High
S	-	17	83	2.83	High
Fe	-	-	100	3.00	High
Cu	-	-	100	3.00	High
Zn	-	33	77	2.60	High
Mn	-	-	100	3.00	High

Nutrient indices of the sub-surface layers indicate that soils, as regards the nutrient status are medium in available nitrogen (2.00), whereas in available phosphorus (3.00), available potassium (3.00), exchangeable calcium (3.00), exchangeable magnesium (3.00), sulphate sulphur (2.83), DTPA iron (3.00), DTPA extractable Cu (3.00), DTPA extractable zinc (2.60) and DTPA extractable Mn (3.00) soils are high in nutrient status.

4.3 LEAF NUTRIENT STATUS

4.3.1 Leaf Macronutrient content

Nitrogen-

Data presented in Table 4.9 showed that leaf nitrogen content of Moringa varied from 2.63 – 3.19 per cent with mean value of 2.88 per cent. The CV for leaf N was found 6.76 which revealed that it vary spatially. The concentration of leaf nitrogen was found sufficient in all the nitrogen collected samples from selected locations of Solan district.

Phosphorus-

Data depicted in Table 4.9 revealed that phosphorous content in leaves varied from 0.74-1.07 per cent with mean value of 0.90 per cent. The CV was 12.44 and thus indicated that it varied spatially. Leaf phosphorous concentration was determined to be adequate in all collected leaf samples of selected locations of Solan district, much like nitrogen and phosphorus.

Potassium-

Data presented in the Table 4.9 revealed that Potassium content for leaves of Moringa ranged between 1.21-1.71% with mean value of 1.36 %. The CV for leaf potassium varied spatially and was found 10.86 %.The Status of Moringa leaves was medium to high in range.

Table 4.9 Leaf nitrogen, phosphorus and potassium contents (%) of Moringa trees in Solan district

Blocks	Locations	Nitrogen	Phosphorus	Potassium
Dharampur	L ₁	3.01	0.97	1.71
	L ₂	2.97	0.93	1.33
	L ₃	3.03	0.98	1.52
Solan	L ₁	2.77	0.88	1.33
	L ₂	2.63	0.74	1.26
	L ₃	2.71	0.81	1.3
Kunihar	L ₁	2.99	1.03	1.27
	L ₂	3.11	0.99	1.43
	L ₃	3.19	1.07	1.49
Nalagarh	L ₁	2.63	0.81	1.23
	L ₂	2.71	0.77	1.21
	L ₃	2.77	0.79	1.27
Range		2.63-3.19	0.74-1.07	1.21-1.71
Mean		2.88	0.90	1.36
SD		0.19	0.11	0.15
CV (%)		6.76	12.44	10.86

Higher amount of leaf nitrogen, phosphorus and potassium in most of the locations might be due to high litter produced and the rate of decomposition. The results are in line with findings of Ameri *et al.* (2014) and Undie *et al.* (2013) where leaf Nitrogen, phosphorus

and potassium were recorded as average of 3.09 per cent, 0.20 per cent, and 0.95 per cent, respectively.

Calcium-

Data revealed in Table 4.10 showed that calcium content of Moringa leaves varied from 2.74- 4.61 per cent with mean value of 3.70 per cent. The CV for leaf Ca was found 16.68 per cent revealed that it vary spatially.

Table 4.10 Leaf calcium, magnesium and sulphur contents (%) of Moringa trees in Solan district

Blocks	Locations	Calcium	Magnesium	Sulphur
Dharampur	L ₁	4.07	0.42	0.67
	L ₂	4.09	0.63	0.55
	L ₃	4.06	0.51	0.47
Solan	L ₁	3.23	0.32	0.39
	L ₂	3.65	0.39	0.37
	L ₃	3.56	0.37	0.31
Kunihar	L ₁	4.61	0.44	0.81
	L ₂	4.34	0.47	0.77
	L ₃	4.16	0.45	0.68
Nalagarh	L ₁	2.97	0.31	0.41
	L ₂	2.74	0.34	0.32
	L ₃	2.91	0.3	0.36
Range		2.74-4.61	0.3-0.63	0.31-0.81
Mean		3.70	0.41	0.51
SD		0.62	0.10	0.18
CV (%)		16.68	23.30	35.43

Magnesium-

Data presented in the Table 4.11 revealed that the magnesium content in the leaves of Moringa ranged between 0.30-0.63 with mean value of 0.41. The CV for leaf phosphorus varied spatially and was found 23.30 per cent.

Sulphur-

Data depicted in table 4.11 revealed that sulphur content in leaves varied from 0.31- 0.81 per cent with mean value of 0.51. The CV was found 35.43 and indicated that it varied spatially.

These findings are in line with Gopalakrishnan *et al.* (2016), Mushtaq *et al.* (2019), and Mensah *et al.* (2012) as they have documented a medium range concentration of calcium, magnesium and sulphur in Moringa leaves.

4.3.2 Leaf Micronutrient content

Iron

Data revealed in the Table 4.11 showed that leaf iron content of Moringa varied from 173.61 to 301.23 ppm with mean value of 224.78 ppm. The CV for leaf Fe was found 18.77 ppm and that it varies spatially.

Table 4.11 Leaf iron, zinc, copper and manganese contents (ppm) of Moringa trees in Solan district

Blocks	Locations	Iron	Copper	Zinc	Manganese
Dharampur	L ₁	251.70	47.31	33.12	283.12
	L ₂	232.32	42.76	30.11	271.63
	L ₃	221.64	49.03	26.74	277.14
Solan	L ₁	197.13	32.25	23.4	243.1
	L ₂	183.64	29.49	24.4	227.3
	L ₃	237.93	34.12	21.7	198.4
Kunihar	L ₁	271.61	41.07	26.7	243.12
	L ₂	264.97	38.19	28.94	254.61
	L ₃	301.23	44.09	34.61	231.19
Nalagarh	L ₁	173.61	29.71	21.14	199.79
	L ₂	184.13	27.16	28.4	204.12
	L ₃	177.45	30.12	29.61	209.34
Range		173.61-301.23	27.16-49.03	21.14-34.61	198.4-283.12
Mean		224.78	37.11	27.41	236.91
SD		42.20	7.61	4.24	30.41
CV(%)		18.77	20.50	15.48	12.84

Copper

Data presented in the table 4.11 showed that copper content in leaves of Moringa ranged between 27.16 to 49.03 ppm with mean value of 37.11 ppm. The CV for leaf Cu varied spatially and was found 20.50 ppm

Zinc

Data depicted in table revealed that Zn content of leaves varied from 21.14 to 34.61 ppm with mean value of 27.41 ppm. The CV was 15.48 and indicated that it varied spatially.

Manganese

Data depicted in table 4.11 revealed that Mn content of leaves varied from 198.4 to 283.12 ppm with mean value of 236.91 ppm. The CV was 12.84 ppm that indicated spatial variation.

Aslam *et al.* (2005) reported 293.47 ppm of Iron content in Moringa leaves. Ameri *et al.* (2014) reported Cu content in leaves of Moringa ranging from 15.67-78.32 ppm with mean value of 42.63 ppm. The leaf Zn content with in the range from 34.45 to 76.34 ppm with mean value of 55.39 ppm was reported by Mensah *et al.* (2012). Ameri *et al.* (2014) had also reported the similar range of Mn content i.e. from 173.9 to 278.7 ppm in tropical and sub-tropical regions of India, which is in line with present findings.

4.3.3 Chlorophyll content (Chl a and b) and Protein (%)

Data depicted in table 4.12 revealed that Chl 'a' content of leaves varied from 8.98 to 19.71 mg g⁻¹ with mean value of 12.38 mg g⁻¹. Chl 'b' content of leaves varied from 8.11 to 13.73 mg g⁻¹ with mean value of 10.60 mg g⁻¹. The CV for Chl 'a' and 'b' is 24.33 and 17.61 mg g⁻¹. Among two types of chlorophyll, Chrophyll 'a' has higher content as compared to cholorophyll 'b'. The given results are in accordance with Dubey and Kapoor (2017) and Wasonowati *et al.* (2019) as they have reported the mean value of Chl 'a' and Chl 'b' within same range i.e. 10.08 mg / 100 gm and 11.28 mg / 100 gm.

Data depicted in Table 4.12 showed that leaf protein content of Moringa varied from 16.43 to 19.93 per cent with mean value of 17.97 per cent. The CV for leaf protein content was 6.76 per cent which revealed that it vary spatially. These results are in accordance with the findings of Oluduro *et al.* (2012) and Mensah *et al.* (2012) because similar range of protein % i.e. 16.78-25.39 % and 17.87- 27.65 % have been reported.

Table 4.12 Chlorophyll content (Chl a and b) and Protein (%) of Moringa trees in Solan district

Blocks	Locations	Chl a (mg/g)	Chl b (mg/g)	Protein (%)
Dharampur	L ₁	11.69	9.75	18.81
	L ₂	10.13	9.31	18.56
	L ₃	11.33	9.63	18.93
Solan	L ₁	9.88	9.13	17.31
	L ₂	8.98	8.27	16.43
	L ₃	9.74	8.11	16.93
Kunihar	L ₁	14.34	12.31	18.68
	L ₂	15.13	13.73	19.43
	L ₃	19.71	12.17	19.93
Nalagarh	L ₁	12.32	11.73	16.43
	L ₂	11.43	10.31	16.93
	L ₃	13.91	12.76	17.31
Range		8.98-19.71	8.11-13.73	16.43-19.93
Mean		12.38	10.60	17.97
SD		3.01	1.87	1.21
CV(%)		24.33	17.61	6.76

4.4 RELATIONSHIP OF SOIL PROPERTIES WITH AVAILABLE SOIL NUTRIENT CONTENTS

Data presented in table 4.1.3 showed relationship of nutrient elements with soil pH, EC and organic carbon contents. The results shows that the EC of the surface layers of the soil is significant and positively correlated with P ($r=0.70^*$), Ca ($r=0.64^*$), Mg ($r=0.83^{**}$), Cu ($r=0.81^{**}$) and Mn ($r=0.76^*$). For the sub-surface layers, soil EC is significant and positively correlated with Mg ($r=0.66^*$), Cu ($r=0.66^*$) and Mn ($r=0.71^*$).

Surface soil E.C content was substantially and positively correlated with soil P, Ca, Mg, Cu and Mn content in surface layers, whereas subsurface soil E.C content was substantially and positively correlated with soil Mg, Cu and Mn content. Similar findings have been reported by Moshki and Lamersdorf (2011) and Sah *et al.* (2002), respectively.

The organic carbon content in the surface layer of soil is significant and positively correlated with N ($r=0.59^*$), P ($r=0.51^*$), K ($r=0.79^{**}$), Ca ($r=0.73^{**}$), Mg ($r=0.79^{**}$) and Mn ($r=0.89^*$). For the sub- surface layers, soil OC is significant and positively correlated with N ($r=0.60^*$), K ($r=0.60^*$), Ca ($r=0.59^*$) and Mn ($r=0.67^*$).

Table 4.13 Relationship (r-values) of soil chemical properties with available nutrient elements of *Moringa* trees in Solan district

Properties Nutrient Element	Soil pH		Electrical Conductivity		Organic carbon	
	Soil depth (cm)					
	0-15	15-30	0-15	15-30	0-15	15-30
N	0.51	0.40	0.41	0.19	0.59*	0.60*
P	0.12	0.09	0.70*	0.40	0.51*	0.16
K	0.51	0.46	0.57	0.50	0.79**	0.60*
Ca	0.21	0.13	0.64*	0.47	0.73**	0.59*
Mg	0.25	0.07	0.83**	0.66*	0.79**	0.58
S	-0.42	-0.36	-0.37	-0.41	-0.46	-0.35
Fe	0.18	-0.07	0.30	0.03	0.42	0.31
Cu	0.28	0.07	0.81**	0.66*	0.65	0.58
Zn	0.42	-0.36	-0.27	-0.41	0.03	-0.35
Mn	0.37	0.38	0.76**	0.71*	0.89**	0.67*

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

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

Organic carbon content in surface soils was significantly and positively correlated with soil N, P, K, Ca, Mg and Mn content, whereas organic carbon content in subsurface soils was significantly and positively correlated with soil N, K, Ca and Mn content. Bhat *et al.* (2017) respectively, have documented similar findings.

Dania (2014) reported a similar observation, a significant and positive correlation between soil OC with Mg (0.31*) and Zn ($r = 0.43^*$).

4.5 RELATIONSHIPS OF SOIL PHYSICAL AND CHEMICAL PROPERTIES WITH PLANT NUTRIENT CONTENTS

Data presented in Table 4.1.4 shows that the surface soil OC had a significantly positive relationship with leaf N ($r = 0.92^{**}$), P ($r = 0.70^*$), Mg ($r = 0.63^*$), Cu ($r = 0.80^{**}$) and Mn ($r = 0.69^*$). The N content in the soil was significant and positively correlated with leaf N ($r = 0.77^{**}$), P ($r = 0.62^*$), k ($r = 0.74^{**}$), Ca ($r = 0.85^{**}$) and Cu ($r = 0.61^*$). The P content in the soil was significant and positively correlated with leaf N ($r = 0.73^{**}$), K ($r = 0.76^{**}$) and Mn ($r = 0.64^*$). The available k is significant and positively correlated with leaf N ($r = 0.82^{**}$), P ($r = 0.70^*$), Ca ($r = 0.96^*$), Fe ($r = 0.78^{**}$) and Cu ($r = 0.74^*$). The soil Ca is significant and positively correlated with leaf P ($r = 0.59^*$), Cu ($r = 0.78^{**}$) and Mn ($r = 0.70^*$). The soil Mg is significant and positively correlated with leaf Mg ($r = 0.74^{**}$), S ($r = 0.73^{**}$) and Cu ($r = 0.79^{**}$). The Fe content in soil is significant and positively correlated with leaf P

($r=0.74^{**}$), Cu ($r=0.71^{**}$) and Mn($r=0.82^{**}$). The Cu content in soil is significant and positively correlated with leaf P ($r=0.61^*$), Ca ($r=0.67^*$), S($r=0.85^{**}$) and Mn ($r=0.67^*$). The available Mn in the soil was significant and positively correlated with leaf N ($r = 0.88^{**}$), Ca ($r=0.73^{**}$), S ($r=0.76^{**}$) and Cu ($r=0.70^*$).

Table 4.14 Relationship (r-values) of surface soil characteristics with leaf nutrient contents of *Moringa oleifera* of Solan district

Leaf soil	N	P	K	Ca	Mg	S	Fe	Cu	Zn	Mn
OC	0.92 ^{**}	0.70 [*]	0.51	0.54	0.63 [*]	0.55	0.57	0.80 ^{**}	0.57	0.69 [*]
N	0.77 ^{**}	0.62 [*]	0.74 ^{**}	0.85 ^{**}	0.48	0.54	0.56	0.61 [*]	0.29	0.52
P	0.73 ^{**}	0.53	0.76 ^{**}	0.31	0.49	0.52	0.27	0.55	0.54	0.64 [*]
K	0.82 ^{**}	0.70 [*]	0.56	0.96 [*]	0.54	0.55	0.78 ^{**}	0.74 [*]	0.44	0.49
Ca	0.57	0.59 [*]	0.50	0.44	0.53	0.47	0.44	0.78 ^{**}	0.30	0.70 [*]
Mg	0.49	0.51	0.50	0.53	0.74 ^{**}	0.73 ^{**}	0.55	0.79 ^{**}	0.54	0.52
S	-0.54	-0.12	-0.39	-0.19	0.12	-0.53	-0.49	-0.18	-0.59	-0.09
Fe	0.45	0.74 ^{**}	0.49	0.51	0.57	0.22	0.32	0.71 ^{**}	0.29	0.82 ^{**}
Cu	0.47	0.61 [*]	0.42	0.67 [*]	0.50	0.85 ^{**}	0.51	0.57	0.50	0.67 [*]
Zn	0.10	0.16	0.03	0.44	0.25	0.08	0.31	0.14	-0.23	0.19
Mn	0.88 ^{**}	0.55	0.41	0.73 ^{**}	0.46	0.76 ^{**}	0.51	0.70 [*]	0.53	0.56

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

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

Data presented in Table 4.1.4 shows that the Sub-surface soil OC had a significantly positive relationship with leaf N ($r= 0.71^{**}$), Ca ($r = 0.67^*$) and Cu ($r=0.81^{**}$). The N content in the soil was significant and positively correlated with leaf N ($r=0.78^{**}$), P($r=0.62^*$), k ($r=0.68^*$), S ($r=0.67^*$) and Mn ($r=0.68^*$). The P content in the soil was significant and positively correlated with leaf N ($r=0.87^{**}$) and K ($r=0.73^{**}$). The available k was significant and positively correlated with leaf N ($r=0.85^{**}$), K ($r=0.60^*$) and Cu ($r=0.75^{**}$). The soil Ca was significant and positively correlated with leaf N ($r=0.58^*$), P ($r=0.60^*$) and Ca ($r=0.64^*$). The soil Mg was significant and positively correlated with leaf Mg ($r=0.76^{**}$) and Cu ($r=0.81^{**}$). The Fe content in soil was significant and positively correlated with leaf K ($r=0.67^*$) and Mn ($r=0.83^{**}$). The Cu content was soil is significant and positively correlated with leaf N ($r=0.78^{**}$), S ($r=0.67^*$) and Zn ($r=0.63^*$). The available Mn in the soil was significant and positively correlated with leaf N ($r = 0.85^{**}$), Ca ($r=0.64^*$) and Cu ($r=0.66^*$).

Table 4.15 Relationship (r-values) of sub-surface soil characteristics with leaf nutrient contents of *Moringa oleifera* of Solan district

Leaf Soil	N	P	K	Ca	Mg	S	Fe	Cu	Zn	Mn
OC	0.71**	0.49	0.55	0.67*	0.49	0.57	0.50	0.81**	0.57	0.50
N	0.78**	0.62*	0.68*	0.44	0.41	0.67*	0.46	0.54	0.48	0.68*
P	0.87**	0.46	0.73**	0.23	0.32	0.48	0.24	0.47	0.49	0.55
K	0.85**	0.53	0.60*	0.49	0.51	0.46	0.44	0.75**	0.48	0.52
Ca	0.58*	0.60*	0.48	0.64*	0.65	0.49	0.48	0.47	0.32	0.37
Mg	0.48	0.44	0.31	0.41	0.76**	0.47	0.51	0.81**	0.43	0.76
S	-0.59*	-0.23	-0.52	-0.25	0.07	-0.55	-0.46	-0.33	-0.64*	-0.28
Fe	0.43	0.50	0.67*	0.47	0.45	0.20	0.26	0.50	0.23	0.83**
Cu	0.78**	0.44	0.31	0.51	0.46	0.67*	0.51	0.41	0.63*	0.36
Zn	-0.59*	-0.23	-0.52	-0.25	0.07	-0.55	-0.46	-0.33	-0.64	-0.28
Mn	0.85**	0.46	0.53	0.64*	0.44	0.47	0.36	0.66*	0.43	0.46

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

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

Surface soils have a higher correlation coefficient in macronutrient components than subsurface soils, according to Moshki and Lambersdorf (2011). Sah *et al.* (2002) had reported a significant and positive relationship between leaf and soil samples which are in the line with the present findings.

The interaction between any soil or plant nutrient may result in many sorts of correlations or a lack of connection. The reason that several nutritional components had poor correlation which might be attributed to the effect of weather, crop size, sample time, ion antagonism, and estimate technique. The extremely strong correlation suggests that any of the two measures may be used to accurately forecast Moringa tree nutritional status (Dania, 2014).

Chapter-5

SUMMARY AND CONCLUSION

The present investigations entitled “**Nutritional survey of Drumstick tree (*Moringa oleifera*) in Solan district of Himachal Pradesh**” was carried out during 2019-2021 in Solan district of Himachal Pradesh with the objective to study the nutritional and fertility status of *Moringa oleifera* and to workout the relationships between soil properties and leaf nutrient content.

5.1 SOIL PROPERTIES

5.1.1 Physical and Chemical properties of soil

5.1.1.1 Soil texture

The soil texture of selected blocks of Solan district revealed that Sand, Silt and Clay content in surface layer (0-15 cm) ranged from 51.20 to 66.60, 10.5 to 27.6 and 10.9 to 22.9 with mean value of 60.21, 21.73 and 17.66. Whereas, sub-surface layer (15-30 cm) with Sand, Silt and Clay content varied from 44.10-65.34, 13.5-27.9 and 13.31-36.1 with the mean value of 56.28, 21.38 and 22.71. A predominant of sandy clay loam soil texture was observed in all selected locations

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

The soil pH in the surface (0-15 cm) and sub-surface (15-30 cm) layers ranged from 6.83 to 7.84 and 7.63 to 8.91 with the mean value of 7.34 and 8.24, respectively.

The soil EC in the surface (0-15 cm) and sub-surface (15-30 cm) layers ranged from 0.33 to 0.55 and 0.27 to 0.49 dSm^{-1} with the mean value of 0.47 and 0.40 dSm^{-1} .

The soil OC content in the surface (0-15 cm) and sub-surface (15-30 cm) layers ranged from 2.03 to 2.64 and 1.97 to 2.51 percent with the mean value of 2.32 and 2.19 per cent.

5.1.2.3 Macronutrient status of soil

The Available N, P and K content in the surface (0 to 15 cm) layers ranged from 310.54 to 458.04, 33.6 to 49.19 and 366.69 to 403.45 kg ha^{-1} with the mean value of 402.53,

42.16 and 385.87 kg ha⁻¹. Whereas N P and K content in sub-surface (15 to 30cm) layers ranged from 319.11 to 414.40, 29.56 to 46.73 and 358.87 to 392.68 kg ha⁻¹ with mean value of 376.11, 38.26 and 378.17 kg ha⁻¹.

The Exchangeable Ca and Mg content in the surface (0 to 15cm) layers ranged from 5.96 to 7.40 and 2.59 to 3.09 [cmol (p+) kg⁻¹] with mean value of 6.60 and 2.87 [cmol (p+) Kg⁻¹]. Whereas, Exchangeable Ca and Mg content in the sub-surface (15 to 30 cm) layers ranged from 5.86 to 7.12 and 2.55 to 3.05 [cmol (p+) kg⁻¹] with mean value of 6.49 and 2.81 [cmol (p+) kg⁻¹].

The sulphate S concentration in surface soils varied from 21.65 to 29.90 Kg ha⁻¹, with a mean value of 26.00 Kg ha⁻¹. For the sub-surface the value ranged from 21.71 to 27.87 [cmol (p+) Kg⁻¹] with the mean value 24.68 [cmol (p+) Kg⁻¹], respectively.

5.1.2.4 Micronutrient status of soil

The DTPA extractable Fe, Cu, Zn and Mn in the surface (0-15cm) soils ranged from 5.92 to 15.04, 1.28 to 4.14, 2.24 to 4.11 and 17.13 to 31.32 mg Kg⁻¹ with the mean value of 10.10, 2.60, 3.32 and 23.57 ppm. Whereas, in the sub-surface (15-30 cm) soils a range from 4.13 to 14.25, 1.05 to 3.44, 2.05 to 4.05 and 16.17 to 29.61 ppm with mean value of 9.46, 2.21, 3.14 and 21.62 ppm was recorded.

5.1.2.5 Total Viable Microbial Count (cfu/g) Bacteria, fungi and actinomycetes

The range of viable microbial count in soil for bacteria, fungi and actinomycetes was recorded (83.77-98.74 × 10⁵ g⁻¹ soil), (81.64-95.13 × 10² g⁻¹ soil) and (8.12-10.53 × 10³ g⁻¹ soil) respectively with a mean value of 91.50 × 10⁵, 87.57 × 10² and 9.47 × 10³ cfu g⁻¹ soil.

5.2 NUTRIENT INDICES OF SOIL

Nutrient indices of surface layers indicate that soils regarding the nutrient status was medium for available N (2.00). However, in case of available P (3.00), available K (3.00), Exchangeable Ca (3.00), Exchangeable Mg (3.00), sulphate S (2.91), DTPA Fe (3.00), DTPA Cu (3.00), DTPA Zn (2.60) and DTPA Mn (3.00) the nutrient status of soils was high.

Nutrient indices of the sub-surface layers indicate that soils regarding the nutrient status was medium in available N (2.00), whereas in available P (3.00), available K (3.00), Exchangeable Ca (3.00), Exchangeable Mg (3.00), sulphate S (2.83), DTPA Fe (3.00),

DTPACu (3.00), DTPA extractable Zn (2.60) and DTPA Mn (3.00), the soils were high in nutrient status.

5.3 LEAF NUTRIENT STATUS

The leaf N, P and K content of *Moringa oleifera* varied from 2.63 to 3.19, 0.74 to 1.07 and 1.21 to 1.71 per cent with mean value of 2.88, 0.90 and 1.36 per cent.

The leaf Ca, Mg and S content varied from 2.74 to 4.61, 0.30 to 0.63 and 0.31 to 0.81 per cent with mean value of 3.70, 0.41 and 0.51 per cent.

The leaf Fe, Cu, Zn and Mn content varied from 173.61 to 301.23, 27.16 to 49.03, 21.14 to 34.61 and 198.4 to 283.12 ppm with mean value of 224.78, 37.1, 27.41 and 236.91 ppm.

The Chl 'a' and Chl 'b' content varied from 8.98 to 19.71 and 8.11 to 13.73 mg g⁻¹ with mean value of 12.38 and 10.60 mg g⁻¹.

The leaf protein content varied from 16.43 to 19.93 percent with mean value of 17.97 percent.

5.4 RELATIONSHIP OF SOIL PROPERTIES WITH AVAILABLE SOIL NUTRIENT CONTENTS

The relationship of soil properties (pH, EC, and OC contents with available nutrient elements) shows that the soil EC of the surface layers of the soil is significant and positively correlated with P, Ca, Mg, Cu and Mn. For the sub-surface layers, soil EC is significant and positively correlated with Mg, Cu and Mn. The soil OC content in the surface layer of soil is significant and positively correlated with N, P, K, Ca, Mg and Mn. For the sub-surface layers, soil OC is significant and positively correlated with N, K, Ca and Mn.

5.5 CORRELATION AMONG THE SOIL CHARACTERISTICS AND LEAF NUTRIENT STATUS

It showed that the surface soil OC had a significant and positive relationship with leaf N, P, Mg, Cu and Mn. The N content in the soil was significant and positively correlated with leaf N, P, K, Ca and Cu. The P content in the soil was significant and positively correlated with leaf N, K and Mn. The available K is significant and positively correlated with leaf N, P, Ca, Fe and Cu. The soil Ca is significant and positively correlated with leaf P, Cu and Mn. The soil Mg is significant and positively correlated with leaf Mg, S and Cu. The Fe content in

soil is significant and positively correlated with leaf P, Cu and Mn. The Cu content in soil is significant and positively correlated with leaf P, Ca, S and Mn. The available Mn in the soil was significant and positively correlated with leaf N, Ca, S and Cu.

It showed that the Sub-surface soil OC had a significantly positive relationship with leaf N, Ca and Cu. The N content in the soil was significant and positively correlated with leaf N, P, K, S and Mn. The P content in the soil was significant and positively correlated with leaf N and K. The available K is significant and positively correlated with leaf N, K and Cu. The soil Ca is significant and positively correlated with leaf N, P and Ca. The soil Mg is significant and positively correlated with leaf Mg and Cu. The Fe content in soil is significant and positively correlated with leaf K and Mn. The Cu content in soil is significant and positively correlated with leaf N, S and Zn. The Mn content in soil was significant and positively correlated with leaf N, Ca and Cu.

5.6 CONCLUSIONS

From the present investigation it may be concluded that soils of all the selected locations with Moring tree cultivation varied from sandy loam to the sandy clay loam with medium levels of N and Zn. Whereas P, K, Ca, Mg, S, Fe, Cu, Zn, Mn content were high. The leaf nutrient status indicated that leaf Ca, Mg and Zn content was in medium range, whereas leaf N, P, K, S, Fe, Cu and Mn content were high in study area. Significant correlation between soil and leaf nutrient content reveal that the two measurements i.e. soil and leaf analysis used in synchronicity exhibit more reliable information on nutritional status and showing trees have good uptake of nutrients from soil.

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Title of Thesis : “Nutritional survey of Drumstick tree (*Moringa oleifera*)
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ABSTRACT

The present study entitled “Nutritional survey of Drumstick tree (*Moringa oleifera*) in Solan district of Himachal Pradesh” was undertaken during in 4 Blocks (Solan, Kunihar, Dharampur, Nalagarh) of Solan district of Himachal Pradesh. From each Block 3 locations were selected and from each location 5 matured trees of *Moringa oleifera* are evaluated for Physical, chemical and microbiological properties of soil. Majority of soil were found to be sandy loam to sandy clay loam. Soil pH was found to be neutral. EC values were in the safe limits ($<0.8 \text{ dS m}^{-1}$). The organic carbon content was high. Soils were high in available P, K, Ca, Mg, SO_4^{2-} , Cu, Fe and Mn. However, available N and Zn content was recorded medium in range. Whereas, leaf N, P, K, S, Fe, Cu and Mn content were high in study area. Chlorophyll and protein content was found appropriate in Moringa leaves. Soil EC was significant and positively correlated with soil P, Ca, Mg, Cu and Mn, whereas Organic carbon content of soil was significant and positively correlated with soil N, P, K, Ca, Mg and Mn. Significant correlation between soil and leaf nutrient content reveal that the two measurements i.e. soil and leaf analysis used in synchronicity exhibit more reliable information on nutritional status and showing trees have good uptake of nutrients from soil.

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