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COMPREHENSIVE EVALUATION OF SOIL MACRO-NUTRIENT STATUS: A CASE STUDY FROM VEGETABLE GROWING AREAS OF SIRMOUR DISTRICT OF HIMACHAL PRADESH, INDIA

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ABSTRACT

This investigation evaluated the soil chemical properties and macro-nutrient status of vegetable growing areas of Sirmour district, Himachal Pradesh, India in February and March, 2020. Fifty sampling locations were randomly selected, and 100 representative soil samples were collected from two depths: surface (0–15 cm) and sub-surface (15–30 cm). The samples were analyzed for available nitrogen (N), phosphorus (P), potassium (K), sulfur (S), and exchangeable calcium (Ca) and magnesium (Mg). The soils were neutral to slightly alkaline in reaction and EC values of all the soil samples were under normal range. The overall soil organic carbon content was medium to high in status. The results also indicated that the soils had a moderate level of available N and high levels of available P, K, S, and exchangeable Ca and Mg. In the surface layer, nutrient concentrations ranged from 250.88 to 501.76 kg ha^{-1} for N, 23.92 to 59.40 kg ha^{-1} for P, 255.36 to 449.12 kg ha^{-1} for K, 25.37 to 65.77 kg ha^{-1} for S, 2.77 to 6.11 cmol(pz) kg^{-1} for Ca, and 1.64 to 4.03 cmol(pz) kg^{-1} for Mg. The sub-surface layer showed a decline in all measured nutrients. These results suggest that while surface soils are relatively fertile, the decrease in nutrient levels with soil depth may impact root development and overall crop productivity. Therefore, tailored soil management strategies are essential to maintain and enhance soil fertility for sustainable vegetable production in this region.

Key words: Soil fertility, Primary nutrients, Secondary nutrients, North-Western Himalayas, Tomato, Soil chemical properties

Introduction

Himachal Pradesh provides sufficient conditions for the production of various horticultural or agricultural crops. The state has diverse agro-climatic conditions due to which it has a great potential of becoming vegetable bowl of the country (Sharma 2011). Hill vegetables can fetch higher prices due to the production of off-season vegetables which cannot be grown in the plains and are in great demand. All the essential nutrients are equally needed for the proper growth of plants. For optimum growth, plants need right proportion of nutrients and supply of essential nutrients is important to sustain the plant growth. Further, the vegetable growers are showing interest in the hybrid/high yielding varieties of vegetables and these are very responsive to the higher doses of nutrients as the nutritional requirement of these varieties is very high. Understanding soil chemical properties and macro-nutrient status is fundamental to sustainable vegetable production, especially in regions with diverse agro-climatic conditions like Sirmour district of Himachal Pradesh, India. Soil chemistry governs nutrient availability, pH balance, and microbial activity, which directly influence plant growth, yield quality, and overall soil fertility (Al-Shammary *et al.*, 2024). As the cornerstone of agricultural productivity, these parameters are essential for devising effective soil management practices that ensure optimal nutrient cycling and improved crop resilience. It is critical for advancing sustainable farming practices and enhancing vegetable production, thereby contributing to food security and environmental conservation.

Mineral nutrition is very essential factor in crop production (Rengel, 1999) but the inadequate and imbalanced supply of nutrients without the application of organics and continuous cropping is deteriorating the soil health which in turn leads to a sharp decline in the agricultural productivity and crop yields. Therefore, unnecessary use of fertilizers should be avoided in order to lower the various yield losses due to the decline of soil fertility. Soil testing procedures are helpful in providing information about the nutrients which are present in excess. In the present scenario, it is necessary to know the status of the nutrients i.e. deficiency and sufficiency levels for the different crops in order to manage the soil fertility in sustainable manner. The management of the soil fertility is very important and the change in the soil fertility is the clear indication that whether the adoption of the management practices is right and sustainable or not. It can be used in identifying the various trends through time and act as a diagnostic tool to measure soil nutrients (Horneck *et al.*, 2011). Different soil testing procedures are used to estimate the nutrients in the soil which can become available to the plants and not the total amount of soil nutrients. Therefore, the evaluation of the status of available nutrients is necessary for the judicious application of fertilizers and assurance of better crop yields which in turn helps in maximizing the profits.

Material and Methods

Location and extent

Sirmour district of Himachal Pradesh is situated between 30° 22' 30" to 31° 01' 20" North latitude and 77° 01' 12" to 77° 49' 40" East longitude. The altitude ranges from 300 to 3000 meters above mean sea level and is the most South Eastern district of Himachal Pradesh. The district occupies 2,825 square kilometres area which is around 5.07 per cent of the state's total geographical area. The district is predominantly mountainous lying between Shivalik ranges. This district is bounded by Shimla district in North, Solan district in North-West and has inter-state boundary in the South with Haryana and Uttar Pradesh and East with Uttarakhand. The river giri originates from the Kotkhai/ Jubbal tehsil of district Shimla, and cuts through the Sirmour district before merging with the river Yamuna near Paonta Sahib. It is the main and the biggest river in the district. Tons and Bata are another two important rivers and are also tributaries of the Yamuna River.

Climate and Soil

The climate of the district depends upon the elevation and varies from sub-tropical to temperate. Average annual rainfall in the district is around 1405 mm. Out of which 90 per cent occurs during monsoon season and maximum precipitation occurs during the months of July to September. The major seasons are winter (November to February), summer (March to June) and monsoon (July to October). The mean maximum and minimum temperature of the district is around 35°C and 5°C, respectively. Mean monthly meteorological data recorded from the '*POWER DATA Access viewer'* web tool (Stackhouse 2021) for the months of January to December have been illustrated graphically in Fig. 1. The soil in the district varies from thin and bare soil of high mountains to rich deep alluvial soil of the valleys. In the hilly area, brown hill soils with high base status soil of humid regions are found and in the southern part, shallow black, brown and alluvial soils are found. The soil texture varies from loamy sand, sandy loam and loam to sandy clay loam.

Sampling and processing

A preliminary survey of the Sirmour district was conducted for the collection of basic information with regard to area and production of vegetable crops. On the basis of information collected, tomato crop was selected. Fifty farmers who were growing the crop in more than 1 Bigha (800 m^2) were selected. Location of the selected sites has been described in Fig. 2. The location coordinates of the sampling sites lies between 30° 38' 19" to 30° 54' 10" North latitude, 77° 11' 48" to 77° 39' 14" East longitude and 762 to 1522 m altitude. One hundred representative surface (0-15 cm) and subsurface (15-30 cm) soil samples were collected from fifty selected locations of Sirmour district in the months of February and March, 2020. From

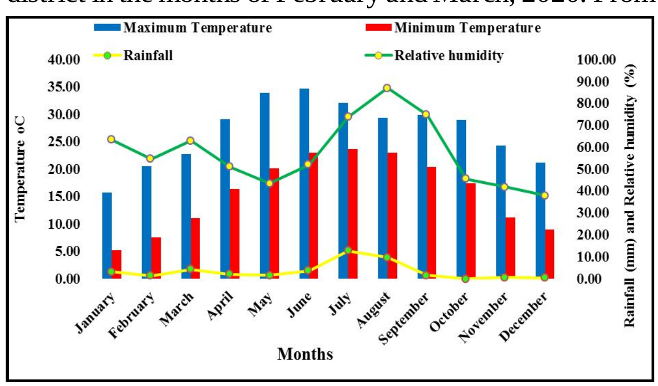

Fig. 1: Mean monthly meteorological data of Sirmour district (Himachal Pradesh).

Table 1: Analytical methods used for soil analysis.

Sr. No.	Soil Property	Method Followed	References
1	Soil pH	Potentiometric method	Jackson (1973)
2	Electrical conductivity	Conductimetric method	Jackson (1973)
3	Organic carbon	Rapid titration method	Walkley and Black (1934)
4	Available nitrogen	Alkaline potassium permanganate method	Subbiah and Asija (1956)
5	Available phosphorus	Olsen's method	Olsen *et al.*, (1954)
6	Available potassium	Ammonium acetate method	Jackson (1973)
7	Available sulphur	Turbidimetric method	Chesnin and Yien (1950)
8	Exchangeable calcium	Flame photometric method	Jackson (1973)
9	Exchangeable magnesium	Atomic absorption spectrophotometric method	Jackson (1973)

each site/location, two soil samples were collected from a depth of 0-15 cm (surface) and 15-30 cm (sub-surface). To avoid contamination, the samples were collected with stainless steel auger and spade. The soil samples were air dried in shade and ground with the help of wooden pestle and mortar and passed through a sieve of size 2 mm. The processed samples were then stored in cloth bags for further laboratory analysis.

Laboratory studies

The processed soil samples were analyzed for soil chemical properties such as soil pH, electrical conductivity & organic carbon content and macro-nutrient status *viz.*

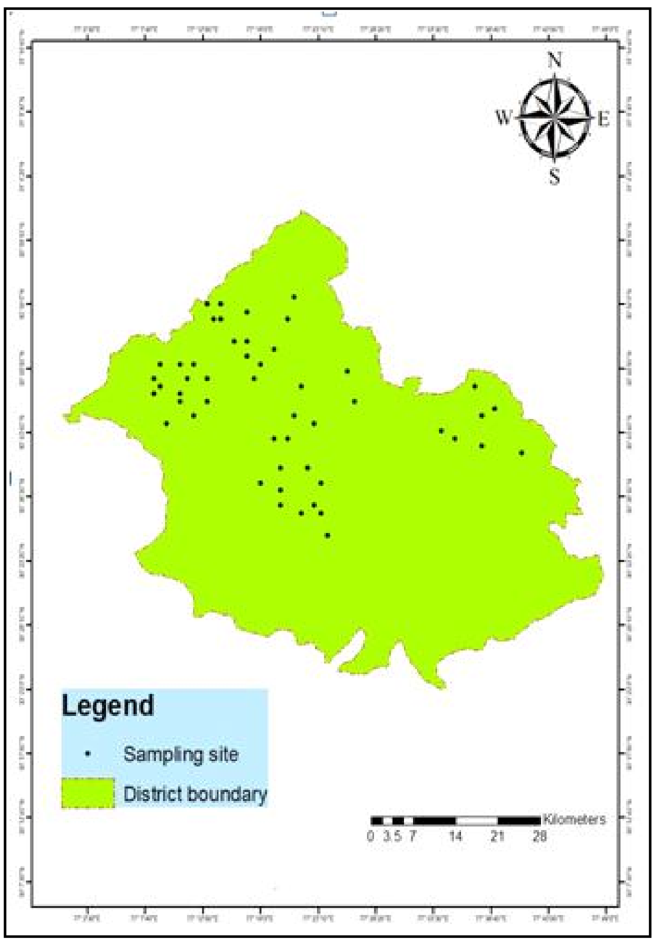

Fig. 2: Location map of selected sites.

nitrogen, phosphorous, potassium and sulphur (kg ha^{-1}), exchangeable calcium and magnesium [cmol (p^{+}) kg^{-1}] by using standard method provided in Table 1. The critical limits of the soil properties were followed for categorizing nutrients and the results were interpreted using these critical limits as given in Table 2.

After classifying the soil samples based on their fertility levels, soil nutrient indices (SNIs) were calculated to indicate the available amounts of each macro and micronutrient at the district level. This was achieved using the formula provided by Parker *et al.*, (1951) as shown below.

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

Where,

SNI = Soil nutrient indices

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

Table 2: Critical limits used for interpretation of macro-nutrient status of the area.

Sr. No.	Nutrient element	Soil fertility class			References
		Low	**Medium**	**High**	
1	Organic carbon (%)	<0.5	0.5-1.5	>1.5	Bhandari and Tripathi (1979)
2	Available N (kg ha^{-1})	<280.0	280.0-560.0	>560.0	FAI (1977)
3	Available P (kg ha^{-1})	<10.0	10.0-24.6	>24.6	FAI (1977)
4	Available K (kg ha^{-1})	<98.6	98.6-280.0	>280.0	FAI (1977)
Secondary macronutrients					
Sr. No.	**Nutrient element**	**Deficient**	**Sufficient**	**Reference**	
1	Available sulphur (kg ha^{-1})	<22.40	>22.40	Tandon (1991)	
2	Exchangeable Ca [cmol (p^{+}) kg^{-1}]	<1.5	>1.5	Tandon (1989)	
3	Exchangeable Mg [cmol (p^{+}) kg^{-1}]	<1.0	>1.0	Tandon (1989)	

Table 3: Status of available nitrogen and phosphorus (kg ha^{-1}) in the soils of tomato growing areas of Sirmour district.

Site No.	Block	Village	Nitrogen (kg ha^{-1})		Phosphorus (kg ha^{-1})	
			Soil depth (cm)			
			0-15	15-30	0-15	15-30
1	Nahan	Banogta	344.96	313.60	44.33	40.25
2		Mahipur	313.60	284.24	35.58	32.08
3		Bechar Kabag	344.96	313.60	42.58	41.42
4		Kandal	282.24	250.88	31.50	28.58
5		Parara	501.76	470.40	54.25	50.17
6		Mehdon Patarag	376.32	344.96	41.42	36.75
7		Panyali	376.32	344.96	51.33	46.08
8		Khano Khanani	407.68	376.32	44.33	42.58
9		Nehar Sawar	376.32	344.96	46.08	43.75
10		Runja Chanar	282.24	250.88	26.83	23.92
11	Pachhad	Paprana	407.68	376.32	26.25	23.92
12		Lana Bhalta	407.68	376.32	32.08	30.92
13		Baru Sahib	439.04	407.68	50.17	47.25
14		Lana Machher	282.24	250.88	31.50	29.75
15		Lana Marag 1	282.24	250.88	26.25	24.50
16		Lana Marag 2	344.96	313.60	25.67	23.92
17		Katyana Serta	250.88	219.52	23.92	20.42
18		Lana Baka	344.96	313.60	25.08	23.33
19		Arka Bardhyog	376.32	344.96	26.25	23.92
20		Bhelan	282.24	250.88	30.33	28.58
21		Malhog Lal Tikker	313.60	282.24	25.67	23.33
22		Pajopad	376.32	313.60	51.33	47.25
23		Narag	313.60	250.88	28.00	26.83
24	Rajgarh	Mariog	344.96	313.60	28.58	27.42
25		Karganu	313.60	250.88	39.67	37.33
26		Dhanech	313.60	282.24	38.36	35.27
27		Batol	376.32	344.96	44.55	42.70
28		Ghil Pabiyana	439.04	376.32	45.17	42.70
29		Kotli	407.68	376.32	47.65	43.93
30		Salana	313.60	282.24	38.36	34.03
31		Mewag jon	470.40	407.68	50.74	48.27
32		Kot	282.24	250.88	43.31	41.46
33		Dimbar	376.32	313.60	40.22	37.75
34		Reri Gausan	313.60	282.24	25.99	24.13
35		Thor Kolan	313.60	282.24	51.98	48.27
36		Kheri Chowki	344.96	313.60	34.03	31.56
37	Sangrah	Bhulti	376.32	313.60	29.08	25.99
38		Pharog	376.32	313.60	33.41	29.70
39		Methli	313.60	250.88	26.61	23.51
40		Nahog	376.32	344.96	40.84	37.13
41		Rerli	344.96	282.24	35.27	32.80
42		Gavahi	313.60	282.24	53.22	51.36
43		Kuftu	376.32	344.96	50.74	48.27
44	Shillai	Panog	376.32	313.60	43.31	40.84
45		Gumrah	313.60	250.88	31.56	28.46
46		Raasat	344.96	282.24	53.83	51.36
47		Balh-Behral	407.68	344.96	47.65	43.31
48		Manal	344.96	313.60	47.03	43.31
49		Laja-Manal	313.60	282.24	59.40	57.55
50		Rohnat	376.32	344.96	33.41	31.56
Range			**250.88-501.76**	**219.52-470.40**	**23.92-59.40**	**20.42-57.55**
Mean			**351.86**	**311.76**	**38.69**	**35.99**
SE±			**2.77**	**2.90**	**1.60**	**1.61**
CV (%)			**14.77**	**16.43**	**25.73**	**26.89**

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.

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

Statitsical analysis

Descriptive statistics, including ranges, means, standard errors, and coefficients of variation, were computed for each parameter, following the method described by Gomez and Gomez (1984).

Results and Discussion

Available N

The data on the status of available nitrogen have been presented in Table 3 which showed that the available nitrogen content in the surface layer (0-15 cm) varied from 250.88 to 501.76 kg ha^{-1} with an average value of 351.86 kg ha^{-1}. Whereas, in the sub-surface layer the available nitrogen content varied from 219.52 to 470.40 kg ha^{-1} with an average value of 311.76 kg ha^{-1}. The CV of 14.77 and 16.43 per cent for available nitrogen content indicates that, it varied spatially in both the surface and sub-surface depths, respectively. The highest content in surface (501.76 kg ha^{-1}) and sub-surface (470.40 kg ha^{-1}) soil was recorded in Parara village of Nahan. While, the lowest content of available nitrogen in surface (250.88 kg ha^{-1}) and sub-surface (219.52 kg ha^{-1}) soil was recorded in Katyana Serta village of Pachhad block. It is found from the results that the surface horizons of vegetable growing soils had more available nitrogen content and it decreased with the increase in depth. This might be due to the higher amount of organic carbon content in the surface layer of vegetable growing soils responsible for higher amount of available nitrogen. Decrease in available nitrogen content with the increase in depth was also reported by Mahajan *et al.*, (2007), Fayed and Rateb (2013), Kumar and Paliyal (2018), Arshad (2020) and Chandel (2020). Most of the samples had medium content of available nitrogen resulting from the addition of farm yard manure, urea and organic fertilizers by the vegetable growing

Table 4: Status of available potassium and sulphur (kg ha^{-1}) in the soils of tomato growing areas of Sirmour district.

Site No.	Block	Village	Potassium (kg ha^{-1})		Sulphur (kg ha^{-1})	
			Soil depth (cm)			
			0-15	15-30	0-15	15-30
1	Nahan	Banogta	288.96	255.36	30.07	27.81
2		Mahipur	360.64	348.32	31.01	27.62
3		Bechar Kabag	397.60	359.52	48.86	41.72
4		Kandal	347.20	322.56	46.98	43.41
5		Parara	369.60	330.40	65.77	57.69
6		Mehdon Patarag	365.12	313.60	48.48	44.16
7		Panyali	387.52	370.72	62.95	52.99
8		Khano Khanani	443.52	349.44	63.33	54.87
9		Nehar Sawar	423.36	372.96	62.77	53.93
10		Runja Chanar	357.28	321.44	36.64	32.89
11	Pachhad	Paprana	267.68	253.12	53.56	49.42
12		Lana Bhalta	417.76	383.04	59.57	57.32
13		Baru Sahib	393.12	334.88	53.93	42.28
14		Lana Machher	302.40	285.60	43.97	40.78
15		Lana Marag 1	338.24	277.76	32.89	27.81
16		Lana Marag 2	272.16	257.60	34.20	29.69
17		Katyana Serta	397.60	355.04	25.37	23.49
18		Lana Baka	390.88	376.32	44.16	40.78
19		Arka Bardhyog	384.16	331.52	44.72	40.78
20		Bhelan	449.12	430.08	28.19	23.87
21		Malhog Lal Tikker	264.32	255.36	42.85	36.64
22		Pajopad	389.76	333.76	54.87	48.86
23		Narag	302.40	260.96	28.19	24.99
24	Rajgarh	Mariog	376.32	364.00	49.05	40.78
25		Karganu	269.92	264.32	39.09	36.46
26		Dhanech	408.80	381.92	52.38	44.08
27		Batol	390.88	355.04	42.49	39.75
28		Ghil Pabiyana	413.28	399.84	61.87	53.85
29		Kotli	424.48	362.88	54.24	47.19
30		Salana	267.68	255.36	40.14	35.83
31		Mewag jon	347.20	332.64	55.80	52.28
32		Kot	384.16	311.36	42.29	31.92
33		Dimbar	293.44	283.36	50.71	46.80
34		Reri Gausan	389.76	299.04	33.29	29.37
35		Thor Kolan	277.76	253.12	30.94	29.37
36		Kheri Chowki	285.60	267.68	28.59	25.45
37	Sangrah	Bhulti	398.72	366.24	37.59	32.11
38		Pharog	338.24	274.40	34.07	33.29
39		Methli	327.04	320.32	49.15	42.49
40		Nahog	416.64	385.28	55.41	47.78
41		Rerli	397.60	355.04	42.29	35.24
42		Gavahi	293.44	271.04	43.08	35.24
43		Kuftu	408.80	370.72	52.67	49.54
44	Shillai	Panog	418.88	367.36	57.76	52.08
45		Gumrah	402.08	346.08	40.92	38.18
46		Raasat	255.36	252.00	37.20	33.09
47		Balh-Behral	379.68	312.48	46.99	30.74
48		Manal	287.84	274.40	42.10	32.90
49		Laja-Manal	282.24	276.64	35.24	32.11
50		Rohnat	274.40	258.72	50.52	40.34
Range			**255.36-449.12**	**252.00-430.08**	**25.37-65.77**	**23.49-57.69**
Mean			**354.41**	**320.81**	**44.98**	**39.44**
SE±			**3.04**	**2.70**	**1.60**	**1.52**
CV (%)			**16.17**	**15.08**	**23.81**	**24.19**

farmers of the region. The results of the study areas are in accordance with findings of Sharma (2005), Chandel (2013) and Suri (2018) who reported the similar status of available nitrogen in the soils of Sirmour district.

Available P

The data regarding the status of available phosphorous in the soils of vegetable growing areas of Sirmour district is portrayed in Table 3 which revealed that the available phosphorus in surface and sub-surface soil samples varied from 23.92 to 59.40 and 20.42 to 57.55 kg ha^{-1} with mean values of 38.69 and 35.99 kg ha^{-1}, respectively. The highest content of available phosphorous in surface (59.40 kg ha^{-1}) and sub-surface soils (57.55 kg ha^{-1}) was recorded in Laja-Manal village of Shillai block. Whereas, the lowest content of available phosphorous in surface (23.92 kg ha^{-1}) and sub-surface soils (20.42 kg ha^{-1}) was observed in Katyana Serta village of Pachhad block. Available phosphorus content varied spatially in both the surface and sub-surface depths as indicated by the CV of 25.73 and 26.89 per cent, respectively. With the increase in the soil depth, it was found that there was decrease in the available phosphorus content. Higher phosphorous content in the surface soil may be because of the accumulation of fertilizer P in the surface layers of soils due to its low mobility to lower depths and due to the presence of high organic carbon content in the surface layers (Sharma and Sood, 2020). A decrease in available phosphorous content in the sub-surface layers has been also reported by Sharma (2005), Mahajan *et al.*, (2007), Fayed and Rateb (2013) and Chandel (2020). The availability of phosphorous is highly pH dependent and maximum availability is found near neutral pH and most of the soils of our study region are near neutral in reaction which is attributable to its high contents in these soils. The results of the study area are similar with findings of Sharma (2005), Chandel (2013) and Suri (2018).

Available K

Available potassium content varied spatially in both the surface and sub-surface depths as indicated by the CV of 16.17 and 15.08 per cent, respectively (Table 4). The available potassium content exhibited a decreasing trend with the increase in soil depth in all the villages of the

Table 5: Status of exchangeable calcium and magnesium [cmol (p+) kg^{-1}] in the soils of tomato growing areas of Sirmour district.

Site No.	Block	Village	Exchageable calcium (cmol (p$^+$) kg^{-1})		Exchangeable Mg (cmol (p$^+$) kg^{-1})	
			Soil depth (cm)			
			0-15	15-30	0-15	15-30
1	Nahan	Banogta	4.16	4.07	3.31	3.17
2		Mahipur	4.25	3.89	3.19	3.18
3		Bechar Kabag	4.84	4.52	3.58	3.34
4		Kandal	4.59	4.41	3.58	3.42
5		Parara	4.28	3.98	3.55	3.25
6		Mehdon Patarag	4.50	3.86	3.08	2.98
7		Panyali	3.05	2.78	3.62	3.34
8		Khano Khanani	4.29	4.03	3.66	3.56
9		Nehar Sawar	4.99	4.21	4.03	3.97
10		Runja Chanar	4.33	4.11	2.38	2.33
11	Pachhad	Paprana	5.49	5.16	3.89	3.56
12		Lana Bhalta	6.11	5.37	3.52	1.54
13		Baru Sahib	4.62	4.30	3.67	3.13
14		Lana Machher	4.59	4.24	3.33	3.24
15		Lana Marag 1	3.41	2.92	3.02	2.67
16		Lana Marag 2	4.70	4.34	3.00	2.88
17		Katyana Serta	2.77	2.54	2.83	2.31
18		Lana Baka	4.20	3.74	3.14	3.10
19		Arka Bardhyog	3.86	3.49	2.98	2.89
20		Bhelan	3.48	3.01	3.11	2.95
21		Malhog Lal Tikker	4.25	3.92	2.34	2.19
22		Pajopad	4.94	4.46	3.35	2.82
23		Narag	3.88	3.26	2.40	2.27
24	Rajgarh	Mariog	4.47	3.94	2.89	2.43
25		Karganu	3.45	3.16	2.06	1.89
26		Dhanech	4.56	4.19	3.35	3.01
27		Batol	3.75	3.48	2.09	1.78
28		Ghil Pabiyana	5.53	4.53	2.33	2.01
29		Kotli	4.98	4.30	2.97	2.48
30		Salana	3.02	2.74	1.70	1.52
31		Mewag jon	5.79	5.16	2.02	1.79
32		Kot	4.13	3.75	1.92	1.61
33		Dimbar	4.78	4.12	1.64	1.34
34		Reri Gausan	3.72	3.46	1.65	1.61
35		Thor Kolan	3.42	3.18	2.11	1.53
36		Kheri Chowki	3.31	3.00	1.99	1.58
37	Sangrah	Bhulti	3.99	3.37	2.25	2.00
38		Pharog	4.02	3.57	2.10	1.74
39		Methli	3.55	3.20	1.79	1.77
40		Nahog	4.51	4.11	2.33	2.09
41		Rerli	3.73	3.19	2.08	1.89
42		Gavahi	3.32	2.79	1.71	1.57
43		Kuftu	3.69	3.12	2.98	2.76
44	Shillai	Panog	4.87	4.38	1.97	1.74
45		Gumrah	3.21	3.00	2.19	1.73
46		Raasat	3.04	2.87	1.74	1.69
47		Balh-Behral	3.87	3.35	3.36	1.56
48		Manal	4.77	4.43	2.42	2.28
49		Laja-Manal	4.86	4.12	3.16	3.12
50		Rohnat	4.36	3.87	2.76	2.53
Range			**2.77-6.11**	**2.54-5.37**	**1.64-4.03**	**1.34-3.97**
Mean			**4.21**	**3.78**	**2.72**	**2.42**
SE±			**0.36**	**0.35**	**0.42**	**0.46**
CV (%)			**17.73**	**17.73**	**25.37**	**29.30**

study area. This may be due to the more intense weathering and release of labile potassium from organic residues on the surface layer. Similar trend has been also reported by Fayed and Rateb (2013), Singh *et al.*, (2017), Arshad (2020), Chandel (2020) and Salve and Bhardwaj (2020). Most of the samples were high in available potassium content which might be due to the release of labile potassium from potassic and organic fertilizers and nature of parent material which has one time acquired like biotite and quartz mineral assemblage (Pandey, 1966). The results of the study area are in conformity with the findings of Chandel (2013) and Suri (2018) who reported the similar status of available potassium in the soils of Sirmour district.

Available S

The data enumerated in Table 4 revealed that the available sulphur content in surface and sub-surface soil samples varied from 25.37 to 65.77 and 23.49 to 57.69 kg ha^{-1} with mean values of 44.98 and 39.44 kg ha^{-1}, respectively. The highest content of available sulphur content in surface (65.77 kg ha^{-1}) and sub-surface (57.69 kg ha^{-1}) layer was recorded in Parara village of Nahan block. While, the lowest content of available sulphur content in surface (25.37 kg ha^{-1}) and sub-surface (23.49 kg ha^{-1}) layer was found in Katyana Serta village of Pachhad block. Available sulphur content showed the spatial variability in both the surface and sub-surface depths as indicated by the CV of 23.81 and 24.19 per cent, respectively. It was also observed that the available sulphur content decreases with increase in soil depth. The sub-surface soils contained comparatively low amount of available sulphur than surface layer which could be due to lower amounts of organic matter content in sub-surface layer. Similar trend was also recorded by Khajuria *et al.*, (2015), Gyawali *et al.*, (2016), Singh *et al.*, (2017), Arshad (2020) and Chandel (2020). The available sulphur content in both surface and sub-surface soils was found to be sufficient in all the samples, which may be because of nature of parent material i.e. gypsiferrous and ferruginous limestone (Wadia, 1966). The results are in testimony with the findings of Chauhan (2018) who observed that the available sulphur content in surface and sub-surface soils varied from 25.40 to 62.90 kg ha^{-1} in the soils of mango orchards of the study area.

Similar result of the study area was also recorded by Chandel (2013) and Suri (2018).

Exchangeable calcium

The data in Table 5 represents the status of exchangeable calcium content in the soils of the Sirmour district. The data illustrated that the calcium content in surface and sub-surface soil samples varied from 2.77 to 6.11 and 2.54 to 5.37 cmol (p^+) kg^{-1} with overall mean values of 4.21 and 3.78 cmol (p^+) kg^{-1}, respectively. The highest exchangeable calcium content in surface [6.11 cmol (p^+) kg^{-1}] and sub-surface [5.37 cmol (p^+) kg^{-1}] depths was recorded in Lana Bhalta village of Pachhad block whereas, the lowest exchangeable calcium content was observed in Katyana Serta village of Pachhad block for surface [2.77 cmol (p^+) kg^{-1}] and sub-surface [2.54 cmol (p^+) kg^{-1}] layer. The CV of 17.73 and 17.73 per cent for exchangeable calcium content showed the spatial variability in both the surface and sub-surface depths. It was also revealed by the results that the exchangeable calcium content decreased with increase in the soil depth. This may be because of the association of biological accumulation with the biological activity and accumulation from the plants on the surface layer of the soil (Soto and Diazfierroz, 1993) and higher amount of organic carbon on the surface layers as compared to sub-surface layers. Similar trend was also shown by Sharma (2005), Jamaluddin *et al.*, (2013), Khajuria *et al.*, (2015), Kumar and Paliyal (2016) and Arshad (2020). The results showed that all the surface and sub-surface soil samples are found to be sufficient in the exchangeable calcium content which might be due to the neutral pH of the soil and by nutrient management practices like application of organic manures, farm yard manure (FYM) and mixed fertilizers by the vegetable growers of the area. The findings of Chandel (2013) and Chauhan (2018) support the obtained results, who also reported the sufficient calcium content in the study area.

Exchangeable magnesium

The data on the status of the exchangeable magnesium content in the soils of the Sirmour district in presented in Table 5 and the data revealed that the exchangeable magnesium content in surface and sub-surface soil samples ranged from 1.64 to 4.03 and 1.34 to 3.97 cmol (p^+) kg^{-1} with overall mean values of 2.72 and 2.42 cmol (p^+) kg^{-1}, respectively. The CV of 25.37 and 29.30 per cent for exchangeable magnesium content shows that it varied spatially in both the surface and sub-surface depths. Nehar Sawar village of Nahan block recorded the highest exchangeable magnesium content in surface [4.03 cmol (p^+) kg^{-1}] and sub-surface [3.97 cmol (p^+) kg^{-1}] layers. While, the lowest exchangeable magnesium content in surface [1.64 cmol (p^+) kg^{-1}] and sub-surface [1.34 cmol (p^+) kg^{-1}] layers. The exchangeable magnesium content decreased with increase in soil depth which might be due to the association of biological accumulation with biological activity and accumulation from plant (Soto and Diazfierroz, 1993) and due to the decline of OC with increase in depth. This trend is in testimony with the findings of Sharma (2005), Mahajan *et al.*, (2007) and Fayed and Rateb (2013). The overall status of exchangeable magnesium is found to be sufficient in the surface and sub-surface soil samples which may be ascribed to the higher organic matter content and neutral soil pH. Similarly, Chauhan (2018) and Suri (2018) reported that the soils of Sirmour district were sufficient in exchangeable magnesium content.

Nutrient indices of soil

The data presented in Fig. 3 showed in surface soil depth, that the status of available nitrogen was found to be in low category in 2.00 per cent samples. The 98.00, 2.00 and 16.00 per cent of surface soils samples was found to be in medium category with regard to available nitrogen, phosphorous, potassium, respectively. The status of available phosphorous, potassium, sulphur, exchangeable calcium and magnesium was found to be in high category in 98.00, 84.00, 100.00, 100.00 and 100.00 per cent surface soil samples. The nutrient index values for available nitrogen, phosphorus, potassium, sulphur, exchangeable calcium and magnesium, were 1.98, 2.98,

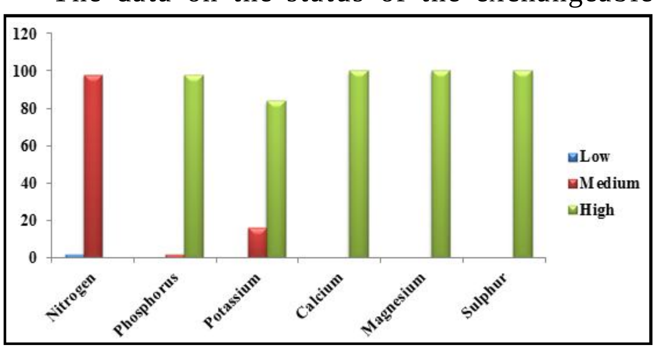

Fig. 3: Per cent surface (0-15 cm) soil samples in different nutrient ranges.

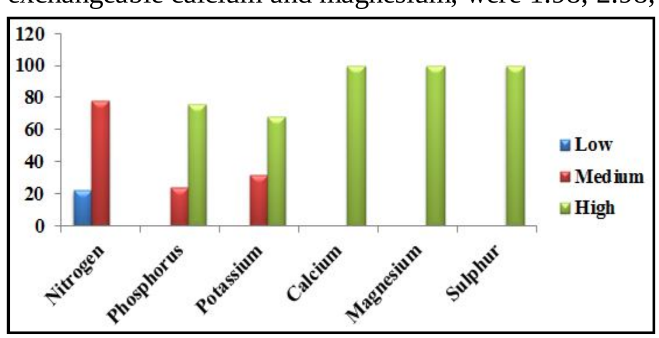

Fig. 4: Per cent sub-surface (15-30 cm) soil samples in different nutrient ranges.

2.84, 3.00, 3.00 and 3.00 respectively. This indicated that nutrient status of the soil samples was in medium category with respect to available nitrogen and in high category with regard to the available phosphorous, potassium, sulphur and exchangeable calcium and magnesium.

In sub-surface soil depth (Fig. 4), the status of available nitrogen, phosphorous, potassium was found to be in medium category in 78.00, 24.00 and 32.00 per cent surface samples, respectively and 76.00, 68.00, 100.00, 100.00 and 100.00 per cent soil samples was found high in available phosphorous, potassium, sulphur, exchangeable calcium and magnesium, respectively. The nutrient index values further showed that nutrient status of the soil samples was in medium category in available nitrogen (1.78) and in high category with respect to the available phosphorous (2.76), potassium (2.68), sulphur (3.00), exchangeable calcium (3.00) and magnesium (3.00).

Conclusions

The comprehensive assessment of soil chemical properties and macro-nutrient status in the vegetable-growing regions of Sirmour district, Himachal Pradesh, revealed that surface soils exhibit moderate to high fertility levels, characterized by neutral to slightly alkaline pH, normal electrical conductivity, and substantial organic carbon content. However, a notable decline in nutrient concentrations with increasing soil depth underscores the necessity for tailored soil management strategies. To sustain and enhance soil fertility for sustainable vegetable production, it is imperative to implement integrated nutrient management practices that combine organic and inorganic fertilizers, as well as adopt soil conservation techniques such as mulching and cover cropping. These measures will ensure the long-term productivity and health of soils in this region.

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