



International Journal of Research in Agronomy

E-ISSN: 2618-0618
P-ISSN: 2618-060X
© Agronomy
NAAS Rating (2026): 5.20
www.agronomyjournals.com
2026; SP-9(6): 09-16
Received: 04-04-2026
Accepted: 10-05-2026

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Cold desert agricultural soil in the North-Western Himalaya: Altitudinal variation in physicochemical parameters and heavy metal analysis

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DOI: <https://www.doi.org/10.33545/2618060X.2026.v9.i6Sa.5665>

Abstract

Soil plays a significant part in determining the sustainable productivity of an agro- ecosystem through the provision of vital nutrients to the developing plants. Extreme climatic and topographical conditions may affect soil qualities at cold desert high altitude. Hence, study was carried out within lower to higher altitudinal clines to examine the changes in soil physico-chemical characteristics of cold desert, in the North-Western Himalayan region of Himachal Pradesh using the appropriate scientific methods. Agricultural soil from three different altitudes were collected for physicochemical characteristics and heavy metals constituents. According to the findings, soil macronutrient levels were increased at higher altitude regions. i.e., Available Phosphorus, Nitrogen and Potassium content in higher altitude was 20.17 ± 2.1 kg/h, 304.26 ± 6.7 kg/h and 491.30 ± 10.4 kg/h respectively but when moved to lower altitude the content in macro nutrients decreased to 5.5 ± 1.8 kg/h (P), 261.33 ± 10 kg/h (N) and 144.8 ± 9 kg/h (K). Soil Colour of higher altitude indicated presence of rich organic carbon in case of heavy metals, higher amounts of copper, lead, and zinc were found in Chitkul., maximum concentrations of Arsenic and Cadmium were in Pooh and maximum concentrations of Nickel and Chromium were in Kalpa. The amount of Cr, Cu and Zn were above the permissible limit in the soil. It appears that the soil in higher altitudinal clines have good properties and indication as compared to lower altitudinal clines. Chitkul soil have two heavy metals that were found above permissible limit.

Keywords: Ethnobotany, medicinal plants, cold desert, North-Western Himalaya, soil analysis, physicochemical properties, heavy metals, and macro nutrients

1. Introduction

In terms of biological diversity, Indian Himalayan Region (IHR) is a mega hotspot. (Verma *et al.*, 2019). Biodiversity plays a key role in influencing socio-ecological and cultural attributes of human societies including livelihood activities of traditional societies living as well as associated to these forests (Herrmann, 2006; Karki *et al.*, 2017; Fartyal *et al.*, 2023) [21, 26, 19]. These ecosystems are highly threatened by anthropogenic activities (Htun *et al.*, 2011; Bisht *et al.*, 2022, 2023) [23, 11, 12]. Poverty, population pressure, agricultural expansion/intensification and infrastructural development are the major threats to biodiversity as well as the environment (Davidar *et al.*, 2010; Awasthi *et al.*, 2022a; Pandey *et al.*, 2023) [16, 7, 38]. Due to the above-mentioned disturbances, the forests and other land use systems have been affected adversely in terms of microbial activities, nutrient cycling and reduced the productivity (Karki *et al.*, 2021; Padalia *et al.*, 2022) [27, 37]. Variations in the region's temperature and altitudinal ranges have created habitats that are exclusive to this area. Concern over soil health and management, techniques has recently increased due to rising pressure on the agricultural industry to increase the production of crops and forage in cold, arid, high-altitude areas (Charan *et al.*, 2013) [14]. Cold deserts cover parts of the Kinnaur and Chamba districts of Himachal Pradesh, the Leh and Kargil districts of Jammu-Kashmir. Lahaul-Spiti region, and the Leh and Kargil districts of Jammu-Kashmir, accounting for about 2.3 percent (74,809 km²) of India's total land area. Cold desert soils have a rough texture, are porous, are barren, have a limited capacity to hold water and nutrients, have few nutrients readily available for growing crops, and behave differently depending on the type of soil (Sharma *et al.*, 2021) [48]. As a source and sink for atmospheric

gases, soil is essential for the growth of crops and other vegetation, which helps to keep the environment clean. Soil is a complex mixture of organic materials, minerals, gases, liquids, and living things that collectively support life. For plant growth and soil management, agricultural chemists value the physicochemical analysis of factors (Addis and Abebaw, 2015) [1]. Cold desert soil lacks essential minerals, there is massive wind erosion, and there is always a water shortage (Kumar and Paliyall, 2016) [30]. In recent years, discussions on the potential impacts of environmental changes on the world's carbon cycle have focused more on high altitude soils. The microorganisms that make up soil are also disturbed by the presence of numerous contaminants in the soil. Numerous physiological, biochemical, and molecular processes are slowed down because of heavy metal stress in soil i.e., poor seed germination, turgor loss, chlorosis, necrosis, senescence, and ultimately plant mortality (Magray *et al.*, 2023) [35]. A decrease in photosynthesis is one of the effects of heavy metal stress. Altitudinal gradients have been used as natural laboratories to study how various climatic factors, such as temperature, precipitation, air pressure, solar radiation, or clear-sky turbidity, affect the biota. Variations in temperature, rainfall, and snowfall have an impact on how quickly organic matter decomposes, which has an impact on how much organic matter builds up at higher elevations. Studying the physico-chemical features of soil in this area is necessary since changes in the microenvironment may have an impact on these soil's physical and chemical properties. Certain heavy metals in soil, such Cr, Mn, Cu, and Zn, come from natural sources and are then somewhat disrupted by human activity (Li *et al.*, 2022) [33]. Numerous soil fertility factors, including their levels of organic matter, pH, cation exchange capacity, phosphate sorption, and phosphorus availability, exhibit significant altitudinal variations. Since the kind of soil

and its physico-chemical behaviour affect crop yield and soil management. The early stages of straw decomposition are impacted by temperature in a substantial way on the phospholipid fatty acid content of the soil. Soil management in such a sensitive agroecosystem is essential for stabilising and sustaining crop production. Altitudinal variation in physicochemical parameters and heavy metal analysis of agricultural soil can demonstrate significant changes, reflecting both natural gradients. The goal of the current study was to understand the physico-chemical characteristics of agricultural soils along altitude gradients in the cold desert high altitude region while taking into consideration the circumstances and problems.

2. Materials and Methods

2.1 Study sites

The study area was Kinnaur i.e., cold desert of Himachal Pradesh, a part of the Indian Himalaya. Its altitude ranges from 2,320 to 6,816 mt. (7,612 to 22,362 ft) and latitude extends from 31.6510° N and 78.4752° E. Spreading over an area of 6,401 km² (altitude 2,471 mt²). Three sampling sites in each location were taken over an altitudinal difference of 300 mt each. The first sampling site was located at Kalpa with an altitude of 3000-3300 mt of the Kinnaur (Fig 1(b)). It is located 265 km beyond Shimla on the NH-5 in Kinnaur district. Chitkul (a village in Kinnaur) is the second site and constituted the third site at an altitude of 2700-3000 m above sea level (Fig 1 b). Second site was Chitkul, which is in Kinnaur district of Himachal Pradesh in India on the right bank of the Baspa River. Pooh, a small town in the Kinnaur area was the third sampling location (Fig 1 b). Its altitude range starting from 2400 mt. upward upto 2700 mt. above sea level.

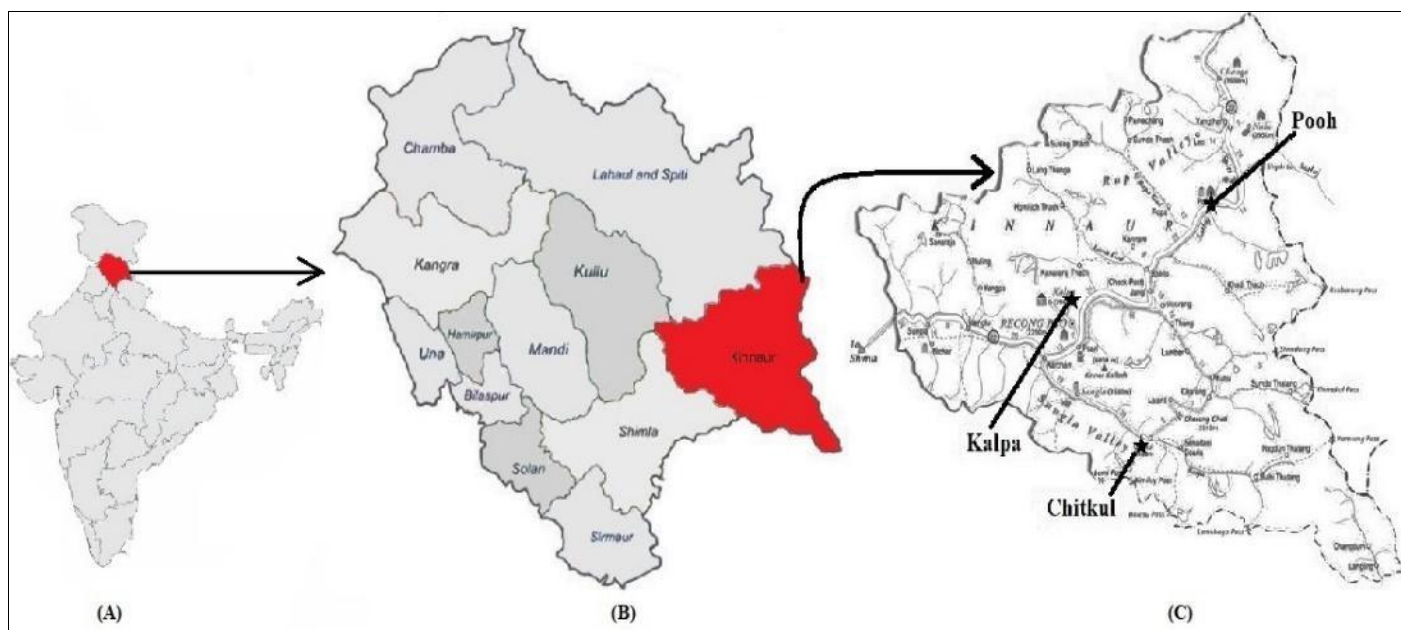


Fig 1: (A) Map of India (B) Map of Himachal Pradesh showing sampling area (C) Map of Kinnaur showing sampling sites

2.2 Soil sampling

A small portion of soil (500 gm) was collected from each sampling site. Soil was dug upto 0 - 20 cm. by employing a tube auger from identified spots match with the locations in zigzag manner. Minimum of three soil samples from each location were taken. The soil samples were collected in polythene bags and with proper labeling.

2.3 Physicochemical characteristics of soil

Physicochemical characteristics of the sample, including colour, pH, Electric Conductivity (EC), organic carbon, available Nitrogen (N), Phosphorus (P), and Potassium (K) were examined. Method of Rice and his coworkers was used to determine soil colour and the Munsell colour chart was also compared. The moisture content of soil was determined by Oven

dry method given by Allen and others in 1974. Soil pH and electrical conductivity was done in soil-water suspension of 1:2 by digital pH and conductivity meter. Nitrogen estimation was done by Micro-Kjeldhal procedure given by Chapman and Pratt in the year 1961. Estimation of Potassium was done Flame photometrically (Piper, 1952) [39]. Phosphorus and Organic Carbon was estimated by wet digestion method (Jackson, 1978) [24].

2.4 Estimation of heavy metals

2.4.1 Methods of soil digestion

1g of each sample was precisely weighed before being put in a 100 mL PTFE beaker. To establish the best suitable digestion method to ascertain the contents of the samples, three different acid digestion methods were applied to the samples i.e., Ni, Fe, Pb, As, Cd, Ni, and Zn in TM samples by AAS. Method A (nitric-perchloric acid digestion 2:1) 5 mL of 65 percent HNO_3 was added to the sample, and the mixture was then gently heated for 30 to 45 minutes. 2.5 mL of 70% HClO_4 were added after cooling, and the mixture was slowly heated until strong white vapours started to form. The mixture was then allowed to cool, 10 mL of deionized water was added, and it was then heated again until all the vapours had been expelled. 2.5 mL of 70% HClO_4 were added after cooling, and the mixture was slowly heated until strong white vapours started to form. The mixture was then allowed to cool, 10 mL of deionized water was added, and it was then heated again until all the vapours had been

expelled. To prevent sample loss during the digestion operations, the inside walls of the beakers were cleaned with 2 mL of deionized water. Finally, the samples were filtered through Whatman 42 (2.5- μm particle retention) filter paper (Hseu, 2004) [22]. Deionized water was then added until the final volume reached 100 mL. Mode of estimation for all the heavy metals was axial and frequency was Cadmium-228.802, Chromium-224.700, Nickel-221.647, Lead- 220.353, Arsenic-189.04 and Zinc-213.856. All data were statistically processed by using Graph Pad Prism 5.

3. Results and Discussion

3.1 Altitudinal variation and climatic conditions of the sites

The details of the study sites are described in Fig 2 (A) shows variation in altitudes. The Altitude of the site has a profound correlation with climatic conditions of the site, as these conditions vary with change in altitude. In the present study maximum air pressure ($707.4667 \text{ Bar} \pm 1.7$) was recorded at the site Pooh (2993 m) and minimum air pressure ($659.6 \text{ Bar} \pm 0.3$) was recorded at site Kalpa (3973.6 m). When atmospheric pressure is high, the rate of transpiration is low (Fig 2 (B)). Relative humidity is directly proportional to temperature and atmospheric pressure which ultimately affects the physiological processes of plants. Maximum relative humidity was ($93.8 \pm 5.7\%$) recorded in site Kalpa. The minimum relative was ($43 \pm 0.1\%$) observed from site Pooh (Fig 2 (C)).

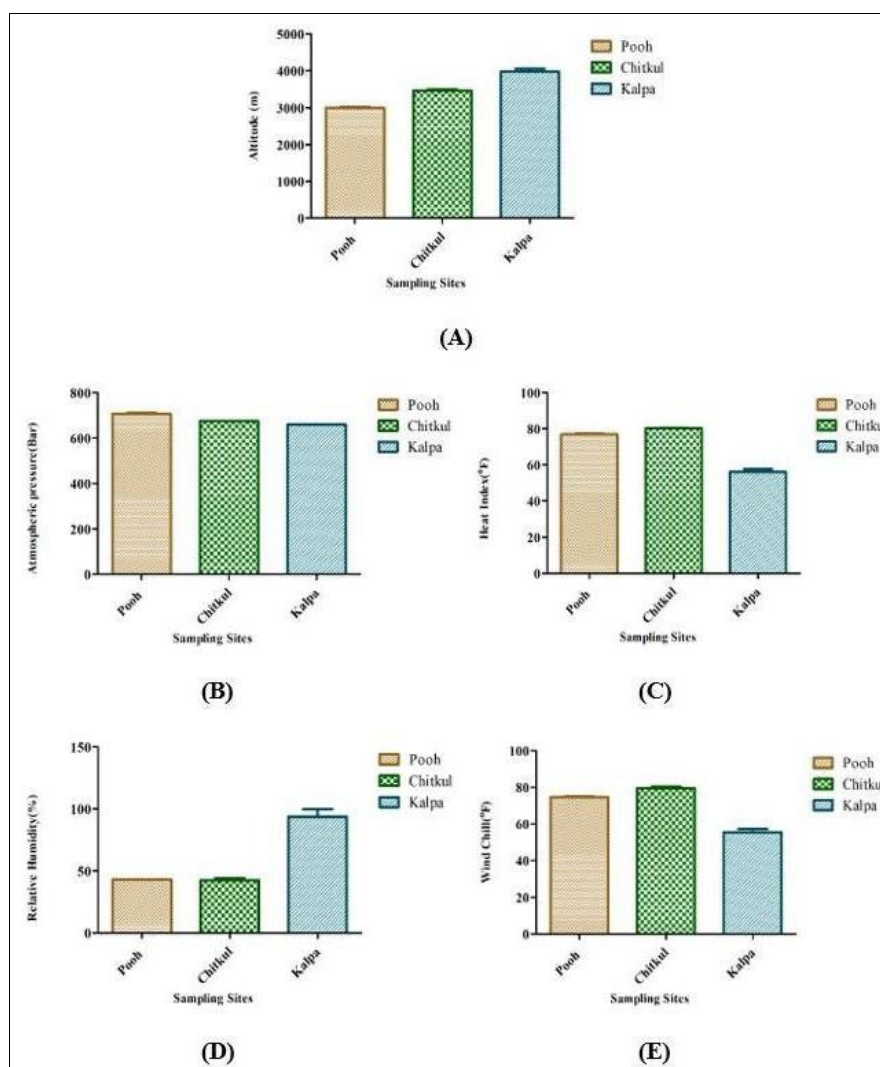


Fig 2: Altitudinal variations (A), Atmospheric pressure (B), Relative humidity (C), Heat index (D) and Wind chill (E) of collected samples

There is a direct correlation between temperature, heat index and relative humidity means as the air temperature and relative humidity increase the heat index (HI) also increases. This fact is supported by the present study in which temperature showed correlation with heat index in both the years having correlation coefficients $r = 0.67$ and $r = 0.74$, respectively. The maximum heat index in both years ($80.2^{\circ}\text{F} \pm 0.2$) was recorded from site Chitkul and the minimum heat index values ($56.2^{\circ}\text{F} \pm 1.4$) were recorded from Pooh (Fig 2 (D)). When temperatures are below 7°C , air motion boosts the rate of heat transmission from a plant's surface to the surrounding atmosphere. So, it can be indirectly related to relative humidity. Maximum wind chill in the year 2014 (79.4 ± 0.7) was recorded from site Chitkul and minimum wind chill (55.5 ± 1.7) were recorded from site Pooh (Fig 2 (E)). When the lapse rate of the ambient temperature is lower at higher altitudes, there may be a potential rise in transpiration rate. This is a result of increased solar radiation absorbed by the plant leaves and the higher density gradient of water vapour from the leaf to ambient air and the greater diffusion coefficient of water vapour in air at lower barometric pressure (Terashima

et al., 1995; Sakata and Yokoi, 2002) [51, 45]. On plant growth the effect of humidity was previously studied by Kawamitsu and co-workers in 1993 in which they find that variations in humidity have an impact on several physiological processes in plants, either directly or indirectly. Reduced evapotranspiration, increased heat load, and increased transpiration all result from low relative humidity, which also affects stomatal closure (Assmann *et al.*, 2000) [6]. Wind chill influences plant physiological processes indirectly, such as transpiration, rather than directly. Wind currents speed up the water vapour emitted during transpiration, removing the surrounding air's saturation, which would otherwise slow down transpiration.

3.2 Physicochemical characteristics of soil

3.2.1 Soil color

Table 1 demonstrates that the soil in Kalpa was darker than that in Pooh and Chitkul, indicating that there was more organic matter present in the soil at higher elevations than at lower elevations.

Table 1: Soil color of soil samples (Munsell color chart)

S. No.	Sample	Soil color in Dry conditions	Soil color in wet conditions
1	Pooh	10YR 6/3 Light Yellowish Brown	10YR 5/2 Dark Yellowish Brown
2	Chitkul	10YR 4/3 Brown	10YR Dark Brown
3	Kalpa	10YR 5/3 Pale Brown	10YR Dark Greyish Brown

In 10YR 6/3: The hue is 10YR, value is 6/ and chroma is /3

3.2.2 Soil Moisture Content (SMC)

If the soil is nutrient-rich, this ability will be enhanced, resulting in a higher moisture content. (Reth *et al.*, 2005) [42]. The maximum moisture content was noted in Kalpa (51.6 ± 1.7) and minimum moisture content in Site Pooh (28.6 ± 0.3) (Fig 3 (A)). Significant differences in moisture were found on a few sites. These results were supported by the results observed by Bhattarai and Mandal in the year 2017, which showed decreasing trend of soil moisture content with increasing altitude in two forests of *Shorea robusta*. Due to the soil's higher concentration of clay, which has a large specific area and a high capacity to absorb water and other chemicals, the moisture content of the soil may be higher (Brady and Weil, 2013) [13].

3.2.3 Soil pH

Studying soil pH is crucial because it affects the amount of soil microbial biomass and other biochemical features, making it just as significant as studying carbon and nitrogen levels (Wardle, 1992) [56]. pH showed minor variability along the elevation gradient. Maximum pH was recorded at site Pooh (7.02 ± 0.1) and minimum pH in Site Kalpa (6.04 ± 0.04) (Fig 3 (B)). In drier regions soil weathering and leaching are less and pH is neutral or alkaline (Arias *et al.*, 2005; Bhattarai and Mandal, 2017) [5, 10]. Increasing salt deposition is more common at lower altitudes than in higher altitude sites, as evidenced by the decreasing pH trend from lower to higher altitude (Northcott *et al.*, 2009; Charan, 2013) [36, 14].

3.2.4 Soil Electrical Conductivity (SEC)

Electrical conductivity of the soil is a significant measure to be examined to comprehend the quality of the soil (Aimrun *et al.*, 2009) [2]. Minimum electrical conductivity was recorded at site Pooh (0.32 ± 0.03) and maximum (0.4 ± 0.03) at Kalpa (Fig 3 (C)). The local biota, bedrock, surficial geology, climate, as well as human effects on the land, all have an impact on the pH and

EC measurements, which can vary substantially (Arias, 2005; Saeed, 2014) [5, 44].

3.2.5 Organic Carbon (OC)

The most crucial element in preserving soil fertility is soil organic carbon, which also has an impact on crop productivity and soil functions. At different altitudes, there is a significant variance in the organic soil carbon content across a variety of landscapes (Twongyirwe *et al.*, 2013) [52]. Maximum organic carbon concentration (2.46 ± 0.1) was measured from site Kalpa and minimum (0.50 ± 0.09) from the site Pooh (Fig 3 (D)). According to research done in 2015 by Dar & Somaiah on the altitudinal variation in Organic Carbon (OC) reserves in temperate forests of the Kashmir Himalayas, India, soil OC increased with rise in altitude at high mountainous terrain. OC helps to bind particles into aggregates, which boosts the cation exchange capacity and water retention capacity of sandy soil and contributes to the structural integrity of soils (Shivakumar and Srikantaswamy, 2012) [49]. The shift in climate at higher elevations and the reduction in organic matter formation along elevation gradients are what cause the OC to increase but the slight decrease in OC could be due to heavy rainfall (Sevgi, 2003; Sevgi and Tecomen, 2009) [47, 46].

3.2.6 Phosphorous

The amount of phosphorous in the soil reveals soil characteristics that promote the growth of a particular plant in a particular location, making it possible to determine the type of vegetation present in the area (Tale and Ingole, 2015). Maximum phosphorous (20.17 ± 2.1) was found in soil from site Kalpa and minimum (5.5 ± 1.8) from site Pooh (Fig 3 (E)). These observations were like results obtained by Vincent *et al.*, in 2014 which indicates that regardless of vegetation type, the concentrations of labile P fractions were expected to decrease with rising elevation and accompanying drops in temperature.

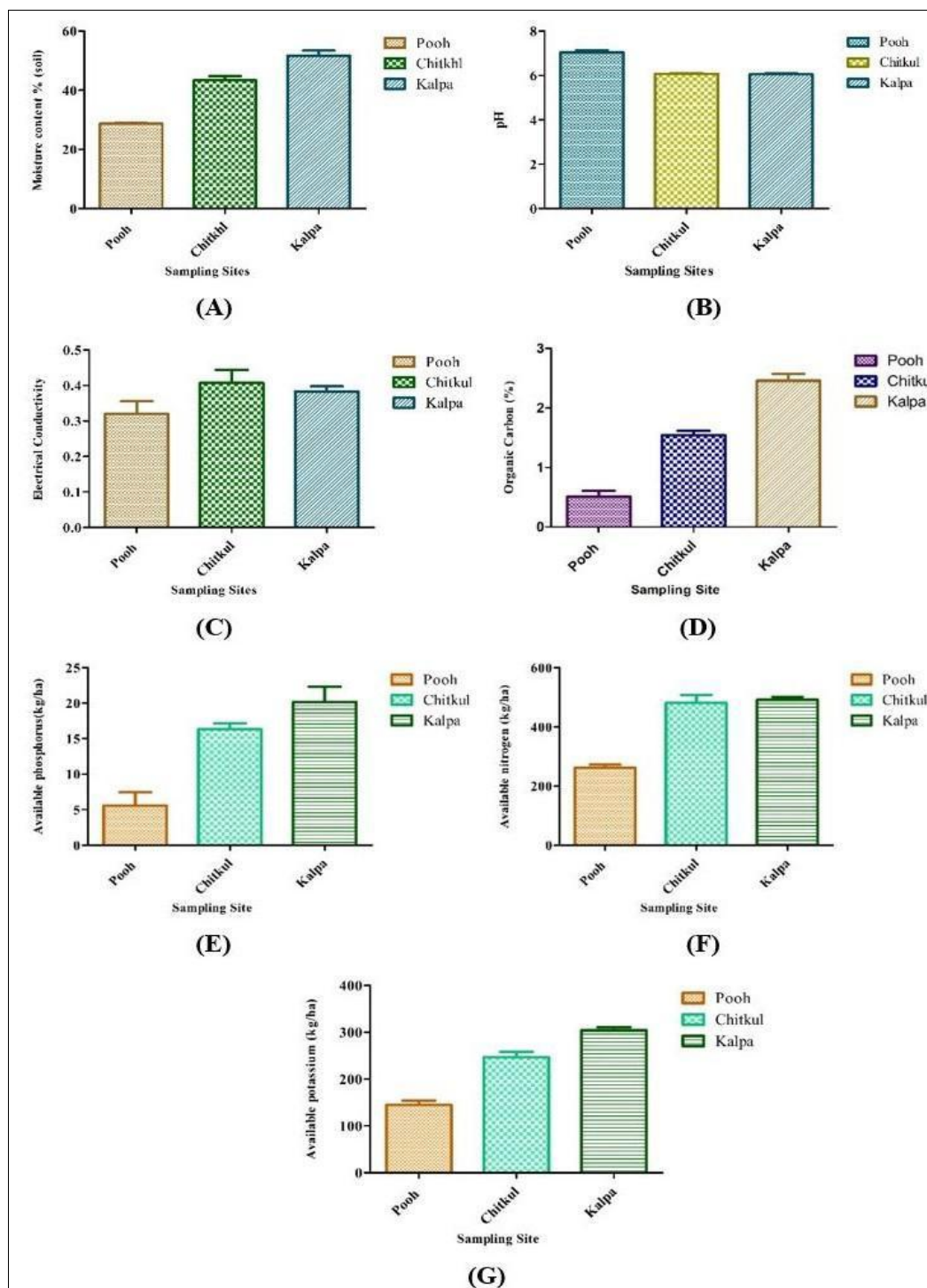


Fig 3: (A) SMC, (B) Soil pH, (C) SEC, (D) OC (E) Available Phosphorus (F) Available Nitrogen, and (G) Available Potassium in soil

3.2.7 Available nitrogen

Nitrates, a highly mobile compound that moves freely with moisture, are the type of nitrogen that is readily available in soil (Gupta and Sharma, 2008) [20]. Maximum nitrogen (491.30 ± 10.4) was observed from the site Kalpa and minimum nitrogen (261.33 ± 10) was observed from site Pooh (Fig 3 (F)). In 1993, Lovett and Lindberg found that due to increasing dry deposition, fog, and cloud water deposition, N deposition along height gradients in the southern Appalachian Mountains rises from 10 kg N ha⁻¹ per year at low elevations to 28 kg N ha⁻¹ per year at high elevations. In 2011, Zhang and his coworkers discovered a positive association between OC and N and noted that these two increases with increasing altitude. Similar observations were observed by Wang *et al.*, in 2016 since there is less N

accumulating at lower elevations due to high temperatures, the N concentration is higher at high altitudes.

3.2.8 Available potassium

Maximum K (304.26 ± 6.7) was found from site Kalpa and minimum (144.8 ± 9) from site Pooh (Fig 3 (G)). Similar observations were recorded by Sevgi (2003) [47] in which K showed highly positive correlation with altitude. Due to improved mineral and rock disintegration in the presence of organic acids, soil K levels increased. (Kumari *et al.*, 2008) [31].

3.3 Heavy metals in soil

The heavy metal contents of the examined soil samples were determined analytically, and the results are given in Fig 4. The

arithmetic mean of Ni, Pb, Cr, Cu, As, Cd and Zn in Pooh area were 2.6 ± 0.08 , 10.24 ± 0.33 , 0.566 ± 0.20 , 181.96 ± 1.59 , 21.56 ± 0.14 , 0.14 ± 0.008 and 86.13 ± 0.68 mg/L, in Chitkul area were 5.38 ± 0.12 , 18.56 ± 0.17 , 1.76 ± 0.08 , 222.80 ± 3.08 ,

17.43 ± 0.29 , 0.056 ± 0.014 and 145.26 ± 0.71 mg/L, and in Kalpa area were 7.38 ± 0.10 , 12.40 ± 0.40 , 8.71 ± 0.344 , 193.66 ± 2.49 , 18.66 ± 0.18 , 0.04 ± 0.020 and 114.20 ± 0.20 mg/L.

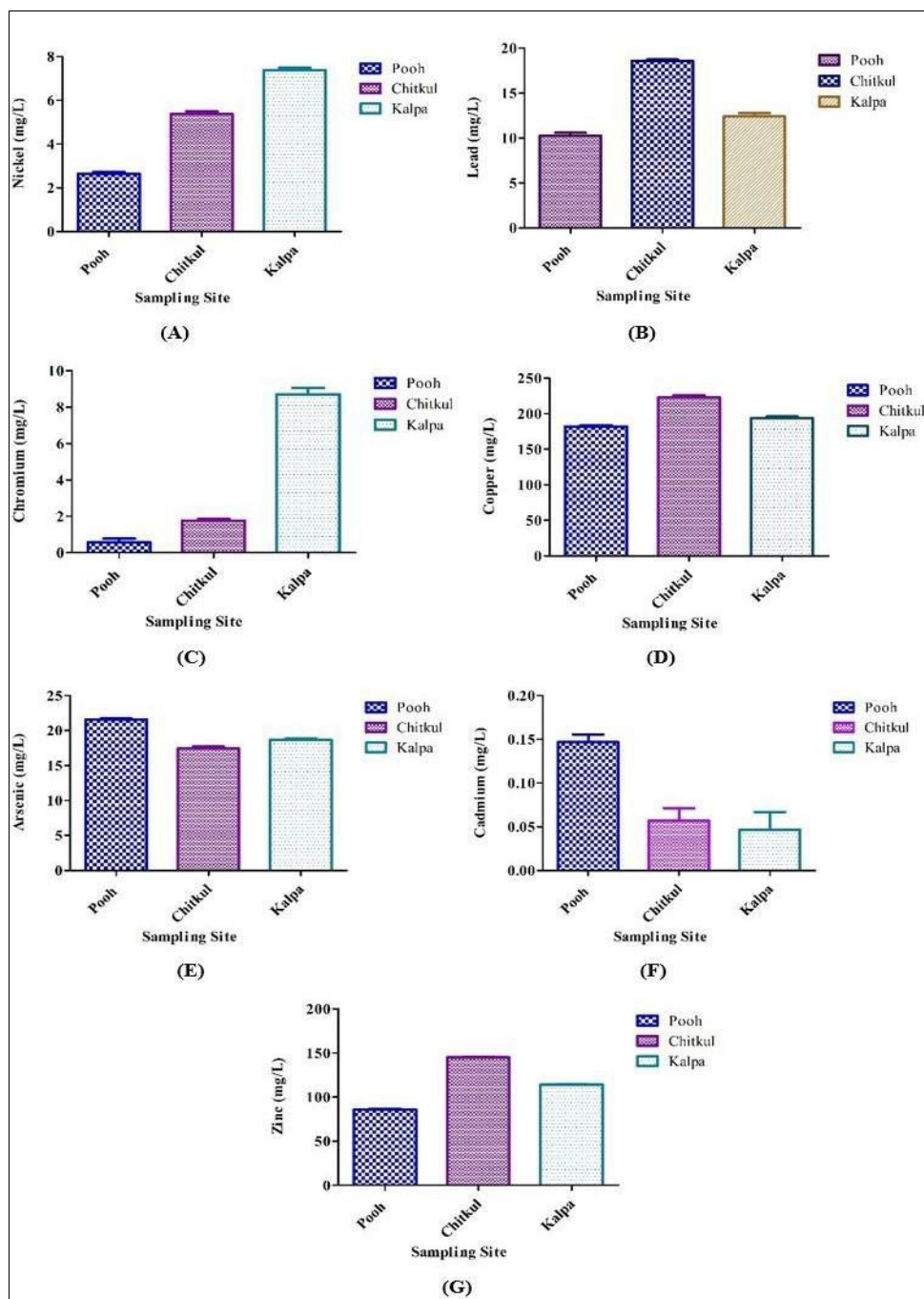


Fig 4: (A) Nickel, (B)Lead, (C) Chromium, (D) Copper (E) Arsenic (F) Cadmium and (G) Zinc Cu, Pb, and Zn concentrations were highest in samples taken from the Chitkul area, As and Cd in Pooh area, Ni and Cr in Kalpa area respectively

Our study shows: $Cu > Zn > As > Pb > Ni > Cd$. The Zn/Cd ratio measures the opposition that Zn imposes on plants' ability to assimilate Cd and reduce its toxicity (Qiu *et al.*, 2011). In general, the extractable fraction values are like those published by Errecalde (1989) [17], Andreu and Boluda (1995) [4], and other authors for soils in the same region, but they are lower than those values (Klessa *et al.*, 1989; Berrow and Burridge, 1990) [29, 9]. According to Eugenia (1996), Cd, Pb, and Cu are among the possibly most hazardous heavy metals for humans and are also the most mobile and the elements that the soil is most adept at retaining are Fe, Co, and Ni. According to Lake *et al.*, (1984)

[32], the extractable form of metals makes up little more than 10% of the overall content and in this sort of soil, the extractable percentage of cadmium could reach 18% of its total concentration. The study on climatic conditions concludes that the factors like atmospheric pressure, wind chill, heat index and relative humidity has greatly increased with increase in altitude with respect to the different selected sites. In addition to the climatic conditions, the physiochemical characteristics of soil have shown a positive correlation in respect with altitude. Soil plays a major role in determining the sustainable productivity of an agro-ecosystem by supplying essential nutrients to the

growing plants and through soil analysis it has been concluded that Kalpa soil was found most efficient amongst all the three sites.

4. Conclusion

Through the provision of vital nutrients to the developing plants, soil plays a significant part in determining the sustainable productivity of an agro-ecosystem. At cold desert high altitude, extreme climatic and topographical circumstances may have an impact on soil characteristics. Based on the soil samples collected from all the three sites, we thoroughly analyzed the soil physicochemical properties (Soil colour, Moisture content, pH, Electrical conductivity, soil organic carbon, nitrogen, phosphorus, and Potassium) and seven heavy metals elements (Cr, Ni, Cu, Zn, Pb, Cd, As). The studies on climatic conditions reveal that the factors such as atmospheric pressure, wind chill, heat index and relative humidity have increased with increase in altitude at different sites. The findings indicate that soils at higher altitudes exhibit greater concentrations of macro nutrients in comparison to those at lower altitudes (such as Pooh), where the levels of macro nutrients decrease. Soil Colour of Kalpa was darker than Chitkul and Pooh which indicated presence of rich organic matter in higher altitude. In addition to the soil color analysis, tests were conducted to determine the Organic Carbon content, revealing that it was highest in the Kalpa region, followed by Chitkul, and then Pooh. Samples collected from the Chitkul area exhibited the highest concentrations of Copper, Lead, and Zinc. In contrast, the Pooh area displayed the highest concentrations of Arsenic and Cadmium. Meanwhile, the Kalpa area contained the maximum concentrations of Nickel and Chromium. The amount of Ni, Pb and Cd were under permissible limit in soil. The amount of Cr, Cu and Zn were above the permissible limit in the soil. Amount of As was below permissible limit except Pooh area. It appears that the soil in higher altitudinal clines (Kalpa) have good properties and indication as compared to lower altitudinal clines (Pooh and Chitkul) and Chitkul soil have two heavy metals that were found above permissible limit.

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