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Variability in soil moisture retention curve with altitude and aspect in northwestern Himalaya

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ABSTRACT

This study investigated soil moisture retention dynamics across different altitudes and aspects in a 2.13 km² conservation reserve in the northwestern Himalaya, ranging from 1,230 to 1,845 m amsl. Soil samples were collected in October 2021 from various altitudes and aspects, with moisture retention curves determined using the pressure plate method at tensions of 0.3, 1.0, 5.0, 10.0 and 15.0 bar. Results revealed that altitude significantly influenced moisture retention, with higher water content observed at increased altitudes. Northern aspects consistently showed greater water retention and available water content compared to western aspects. The study also found that vegetation type played a crucial role, with deodar and mixed oak forests exhibiting higher water content than chir pine forests. Specifically, water content at 0 bar tension ranged from 41.38-48.70 per cent, field capacity (0.33 bar) from 22.51-25.13 per cent and permanent wilting point (15.0 bar) from 9.71-11.78 per cent. Available water content ranged from 12.80-13.52 per cent. These findings underscore the complex interplay of topography, soil characteristics, climate and vegetation in determining soil moisture dynamics, highlighting the importance of understanding these interactions for effective land management and ecological assessments in mountainous regions.

Keywords: Soil moisture; altitude; aspect; water retention; Himalaya; forest ecosystems

INTRODUCTION

Understanding how soil holds onto water in the northwestern Himalaya is a complex puzzle, influenced by a blend of factors like the lay of the land, what the soil's made of and the local climate. These elements work together, causing significant differences in how much moisture the soil retains across various altitudes and slopes. This has huge implications for how water moves through the landscape and how entire ecosystems function.

The direction a slope faces, or its aspect (think north-facing versus west-facing), is especially vital. Different sun exposure and evaporation rates on these slopes directly affect their moisture retention. On top of that, the type and classification of the soil itself are critical. Every soil has its own unique way of holding water and it reacts differently as altitude and aspect change. The terrain's features, like slope and aspect, further fine-tune these dynamics by dictating water flow and shaping soil properties. That's why analyzing these factors is essential for accurately predicting how soil moisture will behave. Getting a grip on these interactions is key for smart land management and effective ecological assessments in the region.

Mountain ecosystems are brimming with tiny climate variations, even over small changes in elevation and these variations significantly impact where plant communities grow and how they're structured (Fatima et al 2022). Scientists often study altitude gradients in alpine areas to figure out how climate change is affecting plant distribution and soil quality, especially since ecosystems can change dramatically across space (Adamczyk et al 2019). The way vegetation shifts with altitude and aspect tells us that temperature, precipitation, wind, sunlight and nutrient availability are the primary drivers (Wani et al 2023). Not only does the type of species vary, but their density also changes from one altitude and aspect to another. This means forest soil plays an impactful role in creating diverse habitats, which then shapes the visible differences in plant life (Oliveira-Filho and Ratter 2002). It's a two-way street: changes in plant communities along an elevation gradient can alter soil characteristics and vice versa.

Mountains are huge players in shaping the physico-chemical properties of soil, including how their slopes face. Studying the relationship between plants and soil along an altitudinal gradient helps us better understand the unique plant communities in Himalayan ecosystems (Anic et al 2010). The composition and structure of a forest are directly influenced by soil quality, showing strong links with various community traits like species richness, density, diversity and canopy cover. Both soil properties and forest composition shift as altitude changes (Malik et al 2021).

The nature of the soil profile, its pH and how nutrients cycle within the soil and trees are crucial indicators of a site's quality. Moreover, vegetation actually improves the soil's structure, its ability to absorb water, its water holding capacity, hydraulic conductivity and aeration (Kumar et al 2004). The soil water retention curve, a vital hydro-physical characteristic, is key to understanding how nutrients move through the soil environment. Generally, as you climb higher, temperatures tend to drop and precipitation tends to increase. This study, proposes that soil moisture retention capacity will change along an altitudinal gradient and across northern and western aspects and that these changes will correlate with other soil characteristics and the vegetation present in the area.

MATERIAL and METHODS

Study area and sampling sites

This research focused on a small, 2.13 km² conservation reserve in the northwestern Himalaya, located between 30°54'15" to 30°54'04" North latitude and 77°07'45" to 77°09'13" East longitude, with elevations ranging from 1,230 to 1,845 m amsl. This area, previously a protected forest and later a sanctuary, was designated a conservation reserve on 7 June 2013, to preserve its wildlife and environment. It lies in Himachal Pradesh's sub-temperate, sub-humid agro-climatic zone (Zone-2), receiving about 1,100 mm of annual precipitation, with over 70 per cent occurring during the monsoon (mid-June to mid-September). Vegetation varies by altitude and aspect: chir pine (*Pinus roxburghii*) dominates lower elevations (below 1,300 m amsl), oak (*Quercus leucotricophora*) at middle elevations (1,300-1,600 m amsl) and at higher altitudes (above 1,600 m amsl), oak is prevalent on western aspects while deodar (*Cedrus deodara*) is more abundant on northern aspects (Fig 1). A critical analysis showed that the number of chir pine trees decreased with increasing altitude, while oak trees increased, with deodar forests appearing on northern aspects at higher elevations and oak forests on western aspects.

Soil and plant sampling

Soil samples were collected in October 2021 month from the different selected altitude and aspects. Soil samples were dried in shade and after drying the soil samples were crushed with wooden pestle and mortar. The samples were then passed through 2 mm sieve and kept in cloth bags for their further laboratory analysis. Sample moisture retention curve was determined by pressure plate method described by Richards and Fireman (1943).

Richard pressure plate extractor was used to determine the moisture retention at 0.3, 1.0, 5.0, 10.0 and 15.0 bar tension (Fig 2). Pressure equipment was used to determine soil moisture characteristics curve (SWCC), available water (AW), relative field capacity (RFC) and air capacity (AC) of soils. To initiate the procedure, the ceramic pressure plate and soil sample were gently placed in the chamber.

This equipment is made up of a porous ceramic pressure plate, an airtight metallic chamber and a pressure regulation system. The chamber and valves were closed and the first target air pressure was applied with the help of regulators, after that open the circuit (consists of valves) to release the desirable pressure inside the chamber. As air pressure rises, pore water inside the sample passes through the plate to the outlet. Once equilibrium was attained at different pressure levels, the relevant valve was closed to prevent water from returning to the ceramic plate. Moisture content before and after oven dry sample was taken at 105°C. Data were used to create a soil moisture curve at different pressure levels.

Fig 1. Dominant tree species and associated vegetation at different altitude(s) and aspect(s) in Shilli Reserve Forest, Solan, Himachal Pradesh

Fig 2. Pressure plate apparatus

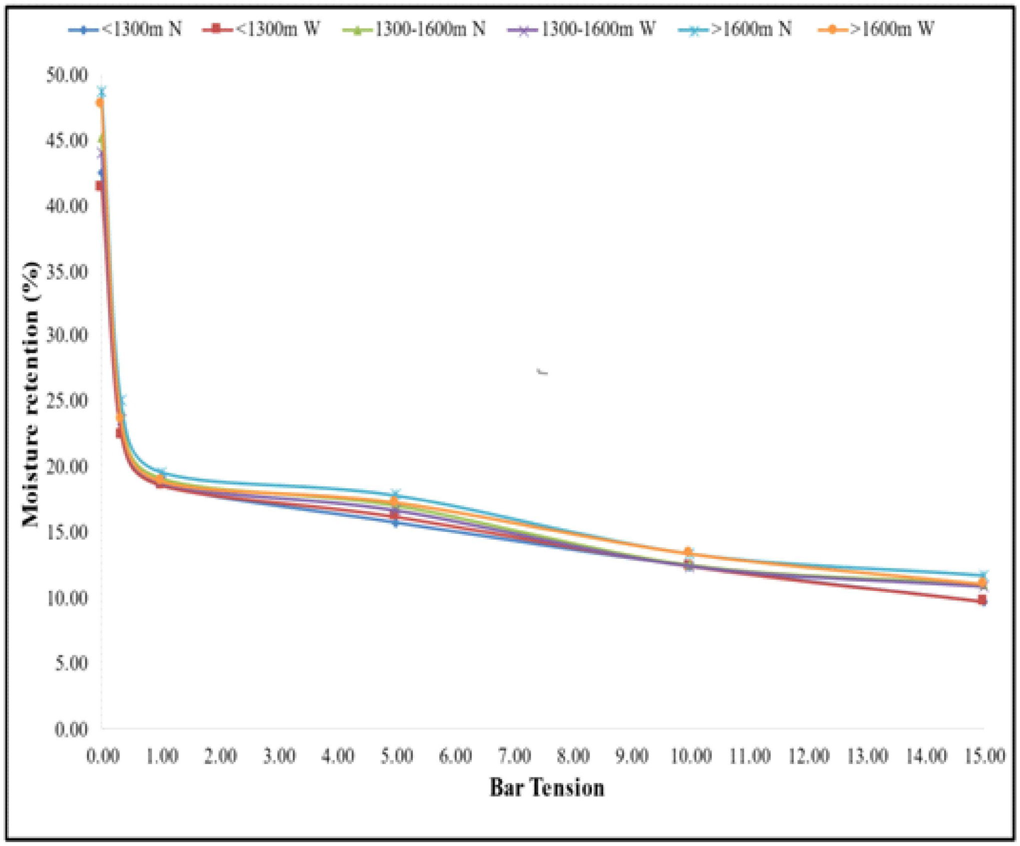

Fig 3. Soil moisture retention at different suction (0, 0.33, 1.0, 5.0, 10.0 and 15.0 bar tension) in soil at different altitude(s) and aspect(s)

RESULTS

Water retention, expressed on a mass (w/w) basis at 0, 0.33, 1.0, 5.0, 10.0, and 15.0 bar tensions (Figs 3, 4), was revealed to be significantly impacted by altitude. Higher water retention was observed at lower tensions, with a decreasing trend as moisture tension increased. Field capacity (0.33 bar tension) was determined to be approximately half (~53%) of the maximum water holding capacity and the permanent wilting point (15.0 bar tension) was about a quarter (~24%) of the water holding capacity.

Water content at 0 (maximum water holding capacity), 0.33 (field capacity), 1, 5, 10 and 15 (permanent wilting point) bar tensions was found to range from 41.38-48.70 per cent, 22.51-25.13 per cent, 18.62-19.67 per cent, 15.77-17.88 per cent, 12.42-13.45 per cent and 9.71-11.78 per cent respectively. A critical analysis of the data indicated that water content at different bar tensions increased with rising altitude and furthermore, northern aspects were observed to favour more water retention compared to western aspects (Figs 3, 4).

Additionally, the type of vegetation was also found to have an impact on water retention, as deodar and mixed oak forests, in the present investigations, exhibited higher water content compared to sole chir pine forest. Available water content (Fig 5) was found to range from 12.80-13.52 per cent. The available water content at different altitudes and aspects is depicted in Fig 3, where an increase in available water was revealed with increasing altitude and northern aspects were observed to have more available water content compared to western aspects, which might be attributed to higher organic carbon at higher altitudes and northern aspects experiencing lesser temperatures.

DISCUSSION

The relationship between water content, altitude, aspect and vegetation type is complex and significantly influences water retention in forest ecosystems. Research indicated that as altitude increases, water content tends to rise, with northern aspects exhibiting greater water retention compared to western aspects. Increased altitude correlates with higher soil water content due to reduced evaporation

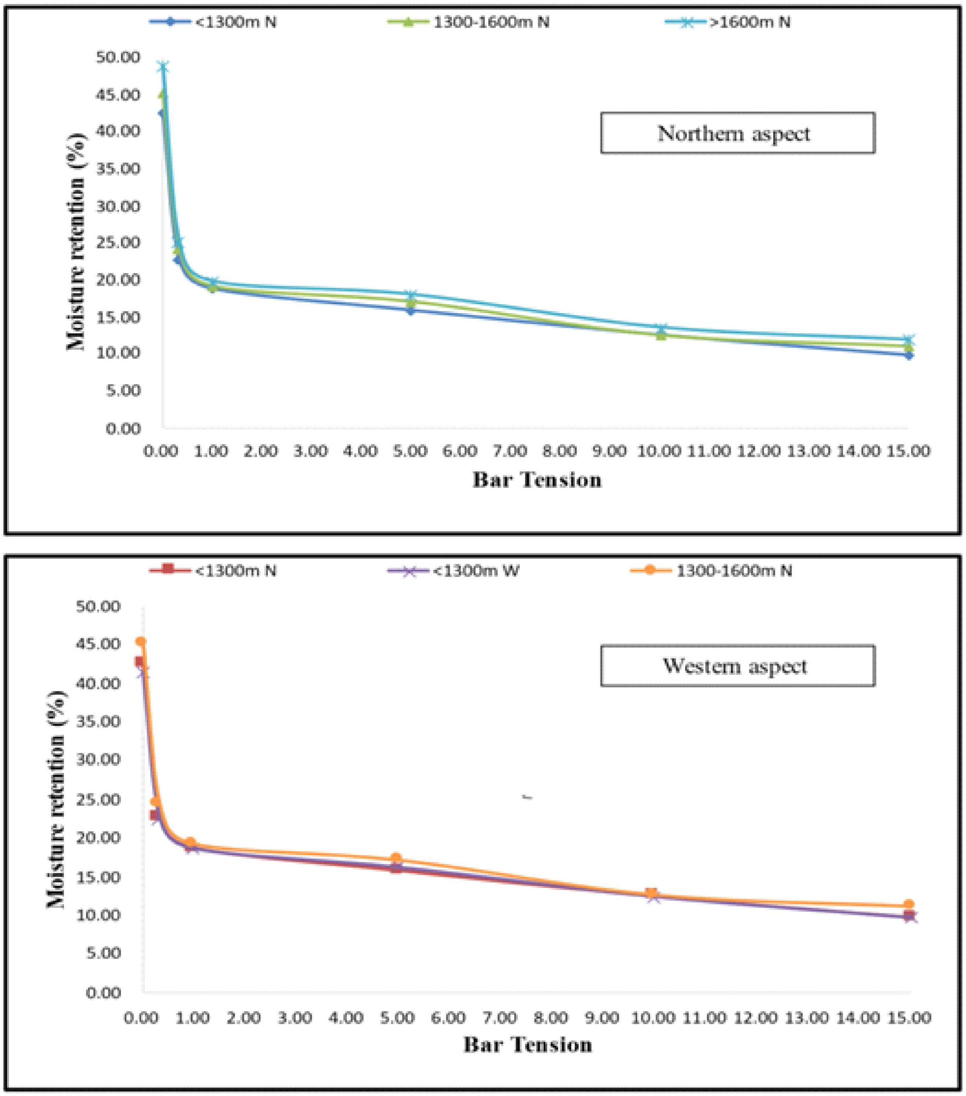

Fig 4. Soil moisture retention at different suction on northern and western aspects

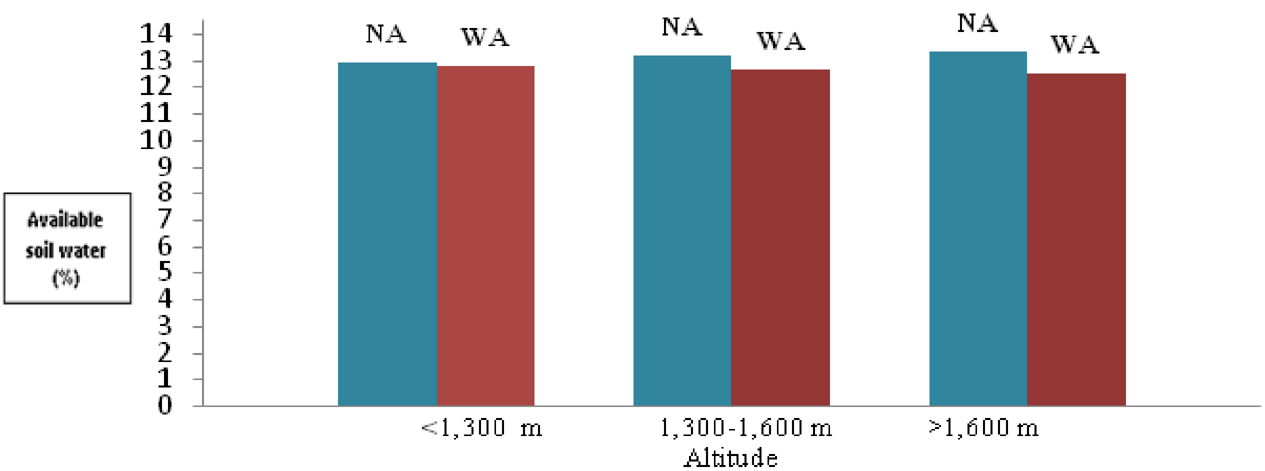

Fig 5. Available water in soil at different altitude(s) and aspect(s)

rates and cooler temperatures (Pichler et al 2009). Studies showed that soil water content varies significantly across altitudinal gradients, with specific measurements indicating differences in water retention capabilities (Pichler et al 2009). In contrast, western aspects experience higher temperatures, leading to increased evaporation and lower available water content (Verma et al 2008).

Different vegetation covers could lead to different soil bulk densities and differences in soil water retention on the three slope aspects (Wang et al 2013). Chir pine forests are detrimental to water availability, causing severe water stress, while deodar and broadleaf mixed forests offer significant relief from water scarcity (Saudamini et al 2019). The accumulation of organic carbon at higher altitudes in northern slopes with deodar forests contributes to improved soil structure and moisture retention. Vegetation on northern slopes plays a crucial role in maintaining soil quality and moisture levels, further supporting higher available water content (Verma et al 2008).

CONCLUSION

This study provides crucial insights into the intricate dynamics of soil moisture retention across varying altitudes and aspects within the northwestern Himalayan forest ecosystems.

The findings clearly demonstrate that altitude significantly impacts soil moisture retention, with higher elevations exhibiting increased water content, likely due to cooler temperatures and reduced evaporation rates. Furthermore, the aspect of a slope plays a critical role, as northern aspects consistently show greater water retention and higher available water content compared to western aspects. This difference is largely attributable to variations in solar exposure and associated evaporation rates.

The research also highlighted the profound influence of vegetation type; deodar and mixed oak forests prove to be superior in maintaining soil moisture compared to chir pine forests, which are associated with greater water stress. The consistent patterns observed in water retention at different pressure tensions across altitude and aspect, along with the variability in available water content, underscore the complex interplay of topography, soil texture, climatic conditions and specific plant communities. Understanding these multifaceted interactions is not merely an academic exercise but is vital for effective land management strategies, particularly in fragile mountainous regions susceptible to hydrological changes. Accurate predictions of soil moisture behaviour are essential for sustainable resource management and robust ecological assessments, paving the way for targeted interventions that can improve water availability and ecosystem resilience in the face of environmental shifts.

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