



Assessment of Low-Cost *In-Situ* Soil Moisture Conservation Measures on Soil Properties and Nutrient Availability in the Chir Pine Forests

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Abstract: The study was carried out in the subtropical chir pine forest located within the Mussoorie Forest Division, Uttarakhand, part of the Western Himalayan region. The study aimed to investigate how low-cost in-situ soil moisture conservation measures affect the soil properties and nutrient availability in chir pine forests. The ranges of pH, electrical conductivity, organic carbon, total nitrogen, available phosphorus and available potassium in the forest soil were 5.56 to 5.71; 0.055 to 0.073 mS/cm; 0.99 to 1.58%; 1.25 to 1.29%; 20.21 to 27.51 kg per ha; and 242.95 to 314.16 kg per ha, respectively. The trend of phosphorus availability for plants changed with changes in the soil pH. The maximum available phosphorus (27.51 kg per ha) was at soil pH of 5.58 in earthen bund treatments. In contrast, the minimum available phosphorus (20.21 kg per ha) was observed at 5.68 soil pH in the pine needle bund + grasses treatment. The highest available potassium was recorded in the pine needle bund treatment (314 kg per ha) at 5.56 pH and the lowest in the shallow ditch treatment (242.95 kg per ha at 5.66 soil pH). The relationship between total nitrogen percentage and organic carbon was positive. The findings highlight that soil moisture conservation treatments have the potential to enhance nutrient availability and fertility in the soil, which will ultimately promote the sustainability of chir pine forests.

Keywords: Low-cost, Soil moisture conservation, Physico-chemical properties, Management practices, Forest ecosystem

The chir pine (*Pinus roxburghii*) is a native tree species of the Himalayas and is commonly found in the Indian states of Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Darjeeling in West Bengal, and Arunachal Pradesh. In Uttarakhand, the chir pine forest contributes the highest area in the forest cover (FSI 2019). Due to the largest forest cover area, this forest acts as the biggest water catchment area for perennial rivers that originate from Uttarakhand, such as the Ganga and Yamuna. These rivers are lifelines for North Indian states.

This forest area received high annual rainfall. The two extremes of rainfall conditions, such as erosion and drought, are greatly mitigated by in-situ soil and water conservation methods (Chimdessa et al., 2019). GLASOD has recognized two types of soil degradation. The first category is soil degradation due to displacement of soil material, such as soil erosion by wind and water. The second category is in-situ soil degradation due to chemical processes like loss of nutrients and organic matter, salinisation, acidification, and pollution, and due to physical processes such as compaction, waterlogging and subsidence (Asio et al., 2009). The land degradation vulnerability covers about 25 percent of land in Asian countries and 46 percent of land in Africa, threatening about 485 million people. The degradation of over 68 percent of the land in Australia poses a severe environmental problem (Mahata and Sharma 2021).

In tropical, subtropical, and semiarid climates, water-induced soil erosion is the main cause of land degradation (Lal 2001, Bhattacharyya et al., 2015). According to the government's unified database (NAAS, 2012), water erosion accounts for 70% of the degradation of 120.7 million hectares of land (Bhattacharyya et al., 2016a). Based on the sedimentation budget across India, the gross average annual soil erosion rate is 15.6 t ha⁻¹ yr⁻¹, (Majhi et al., 2021).

Soil moisture and nutrients are the most essential factors for plant growth (Vaidya et al., 2016, Ademe 2018). The proper use of soil moisture conservation structures helps to reduce the runoff rate and nutrient losses from the soil and improve the soil moisture and nutrient availability for plant growth, which in turn boosts the productivity of land and plants (Vaidya et al., 2016, Gadisa and Midega 2021). In-situ soil and water conservation measures play a significant role in alleviating the two extremes of rainfall conditions, such as erosion and drought. In temperate forest ecosystems, one of the most significant factors influencing tree growth and ecosystem function is the availability of nutrients. Nitrogen and phosphorus are the most limiting nutrients for plant growth, and their resorption is important for plant nutrient conservation (Singh and Negi 2023).

The systematic management of this forest area is essential. The nation's fundamental assets, water and soil, require wise use and conservation to sustain the growing

populations of people, animals, and plants. Low-cost soil and moisture conservation measures have the potential to mitigate soil erosion, enhance water retention, and improve soil health for the sustainable management of forest ecosystems. Therefore, the present study aimed to investigate the impact of low-cost in-situ soil moisture conservation measures on soil properties and nutrient availability. Understanding soil properties and nutrient availability helps in solving the problem of lower productivity of land under chir pine forests through the application of suitable low-cost in-situ soil moisture conservation measures (SMC).

MATERIAL AND METHODS

The present experimental study was conducted in Raipur range, Mussoorie Forest Division, Uttarakhand at an elevation of 1842 m above msl with 30°21' 35.25" (N) latitude and 78°12'16.82" (E) longitude. The annual average rainfall in the region ranges from 2200 mm to 2400 mm. Total eight treatments (Table 1) were applied in the field.

From each treatment, soil samples were collected, pooled, air dried, ground, sieved in a 2 mm sieve and used for soil analysis. The soil of pH and electric conductivity (EC) were analysed using soil:water suspension in 1:2 ratio (Jackson, 1973). The organic carbon (Walkley and Black 1934), total nitrogen (Kjeldahl 1883); available phosphorus (Olsen et al., 1954), available potassium using the flame photometry (Stanford and English 1949) were estimated as per standard methods.

RESULTS AND DISCUSSION

pH: The maximum soil pH (5.71) was in T8 (control) followed by T7 (5.68), T1, T2 and the minimum soil pH (5.56) was in T5 treatment (Table 2). The near to slightly acidic in nature of soil might be due to high material transport with surface water and needle litter falling from the canopy of trees, lower accumulation of needle in control treatment releases lower acidic compounds as they decompose, which can increase

the soil pH value in control treatment compared to other treatments, The soil erosion and slope combine effect may change soil pH from moderately acidic as per present study value to slightly acidic, if soil management and soil moisture conservation practice will not be adopted. Kumar et al. (2013) recorded similar soil pH values at different altitudes, i.e., 700 m (6.77 to 6.27), 800 m (6.97 to 6.536) and 1000 m (6.97 to 6.57). Ramola et al. (2020) observed that in the soil of the temperate forest of Uttarakhand, pH ranges from 5.07 to 5.87, which was acidic due to the result of podzolisation. Vaidya et al. (2016) observed that moisture conservation treatments, i.e., conservation pit (0.45 m x 0.30 m x 0.30 m), ring basin (0.6 m Radius) and half ring basin (0.6 m radius), did not significantly influence soil pH. This could potentially be attributed to a higher concentration of H⁺, Fe⁺², and Al⁺³ ions in the soil, resulting in an acidic pH range across all treatments. Soil pH can be improved by different soil moisture conservation structures such as graded stone bunds (Abay et al., 2016), stone faced soil bunds and soil bunds (Worku, 2017), soil bunds and stone bunds (Kebede et al., 2011), and treated with *Sesbania* spp. and elephant grass (Tamrat et al., 2018). The range of soil pH values required for microbial activity was 5.5-8.8 (Pietri and Brookes 2008ab, Fierer and Jackson, 2006) which also regulates organic matter mineralisation, which includes carbon, nitrogen, phosphorus and sulphur mineralisation (Neina, 2019).

The phosphorus availability for plants changes with changes in the soil pH. The maximum available phosphorus (27.51 kg/ha) was at a soil pH of 5.58 in comparison to all treatments (Fig. 1). T7 treatments observed the minimum available phosphorus (20.21 kg/ha) at a soil pH of 5.68. Soil pH is a limiting factor for the availability of phosphorus in plants. Soil pH plays an important role in the transformation of P in different forms (Wang et al., 2023). The optimum soil pH range for phosphorus availability is 6.0 to 7.0. The lower soil pH in the studied soils is associated with the presence of exchangeable Al, which leads to a decrease in P solubility

Table 1. Details of applied soil moisture conservation treatments in chirpine forest

Treatments	Length (m)	Width (cm)	Depth/height
Shallow ditch- I (T1)	2 m	15 cm	10 cm depth
Shallow ditch - II (T2)	2 m	25 cm	15 cm depth
Shallow trench (T3)	2 m	40 cm top, 20 cm base	15 cm depth
Earthen bund (T4)	2 m	15 cm	15 cm height
Pine needle bund (T5)	2 m	20 cm	15 cm height
Earthen bund + Grasses (T6)	2 m	20 cm	15 cm height
Pine needle bund + Grasses (T7)	2 m	15 cm	10 cm height
Control (T8)		no soil work	

and an increase in non-labile P pools (Hou et al., 2014). At lower pH levels, phosphate tends to bind with iron or aluminum compounds in the soil, making it less accessible for plant uptake. Acidic soils inhibit the chemical reactions that release phosphorus from organic matter and minerals, resulting in lower levels of available phosphorus. The low pH and the high exchangeable acidity in soils due to high amounts of Fe and Al are responsible for P sorption (Turrión et al., 2008).

The highest available potassium was in the T5, i.e., 314 kg per ha at 5.56 pH, and the lowest in the T1 at 5.66 soil pH (Fig. 2). The relationship between the available potassium and soil acidity is difficult to predict. Kozak and Joarder (2005) reported a positive relationship between potassium and pH, but they concluded that potassium is a basic cation, although less important than calcium and magnesium, and soil acidification results from the leaching of basic cations from soils. The pH of the soil influences the release of potassium by altering the concentrations of potassium in solutions that are in equilibrium with the soil, and these concentrations are higher in acidic solutions. Semy and Singh reported that soil pH has a strong positive correlation (0.0787) with soil.

The T8 treatment recorded the highest electrical conductivity (0.073 mS/cm), followed by the T7 (0.073 mS/cm) and T4 (0.071 mS/cm) treatments, respectively. The lowest electrical conductivity (0.055 mS/cm) was in T5 treatments. The EC was non-significant among the treatments. This might be due to organic manures not containing salts and hence there was no influence of organic manure salt accumulation in soil. Soil EC was improved by different soil moisture conservation structures, such as stone faced soil bunds and soil bunds (Worku, 2017), lands treated

with sesbania and elephant grass (Tamrat et al., 2018), soil bunds, integrated manure and soil bunds (Zikri et al., 2015). Vaidya et al. (2016) concluded that EC did not show significant differences due to moisture conservation methods. Acidity in soil can lead to the presence of higher concentrations of certain ions, such as hydrogen ions (H⁺) and aluminum ions (Al³⁺). These ions can compete with other nutrients like calcium (Ca²⁺), magnesium (Mg²⁺), and potassium (K⁺) for adsorption sites on soil particles. This can alter the ionic balance in the soil solution, affecting its electrical conductivity.

Organic carbon: The soil organic carbon was significantly influenced by different treatments; maximum (1.58%) organic carbon was observed in T4, followed by T6, T7, T1 and minimum (0.99%) was in T5 treatment in comparison to all treatments. Hailu et al. (2012) observed the highest soil organic carbon in the Fanya juu 10-year old (1.94%), followed by the Fanya juu 5-year old (1.92), compared to the control (1.68). Gebreselassie et al. (2009) also reported that higher OC in the SMC treatments (9 years old soil bund (3.17%) . In acidic soils, the breakdown of organic matter might be slower, leading to the accumulation of partially decayed organic materials. These materials can help improve soil structure, water retention, and aeration. The increase in organic carbon also increased the percentage of total nitrogen (Fig. 3). Microbial activity may drive a shift in nutrient stoichiometry, leading to an increase in the percentage of total nitrogen as organic carbon levels rise. This type of effect was observed in the T1, T3, T4, T6, and T7 treatments. The T2, T5, and T8 treatments observed a plummet in the total nitrogen percentage due to the lowering of soil organic carbon.

Plants require a lot of nitrogen (N), a soil component that,

Table 2. Physico-chemical properties of soil under different soil moisture conservation treatment applied in chirpine forest

Treatments	(Mean ± SD)											
	pH		EC		OC		Total Nitrogen (%)		Available P (kg/ha)		Available K (Kg per	
T1	5.66±0.11		0.070±0.014		1.40±0.40		1.28±0.03		26.89±10.94		242.95±63.3	
T2	5.62±0.17		0.068±0.016		1.35±0.36		1.26±0.03		22.74±6.63		273.84±100.1	
T3	5.62±0.09		0.065±0.015		1.26±0.43		1.29±0.04		25.91±9.32		272.94±70.7	
T4	5.58±0.17		0.071±0.011		1.58±0.60		1.28±0.04		27.51±7.88		268.80±48.1	
T5	5.56±0.21		0.055±0.007		0.99±0.24		1.25±0.05		26.25±13.81		314.16±114.2	
T6	5.58±0.13		0.065±0.009		1.48±0.50		1.29±0.03		24.46±6.05		288.77±85.9	
T7	5.68±0.15		0.073±0.014		1.42±0.45		1.27±0.03		20.21±6.78		286.91±109.8	
T8	5.71±0.23		0.073±0.015		1.08±0.22		1.26±0.06		26.00±8.57		279.72±121.9	
	F Value	Pr(>F)	F Value	Pr(>F)	F Value	Pr(>F)	F Value	Pr(>F)	F Value	Pr(>F)	F Value	Pr(>F)
	1.088	0.38	2.833	0.0115 *	3.0093	0.0079 **	1.2664	0.2792	0.802	0.589	0.546	0.797

Significance Level: 0 ***** 0.001 **** 0.01 *** 0.05 *

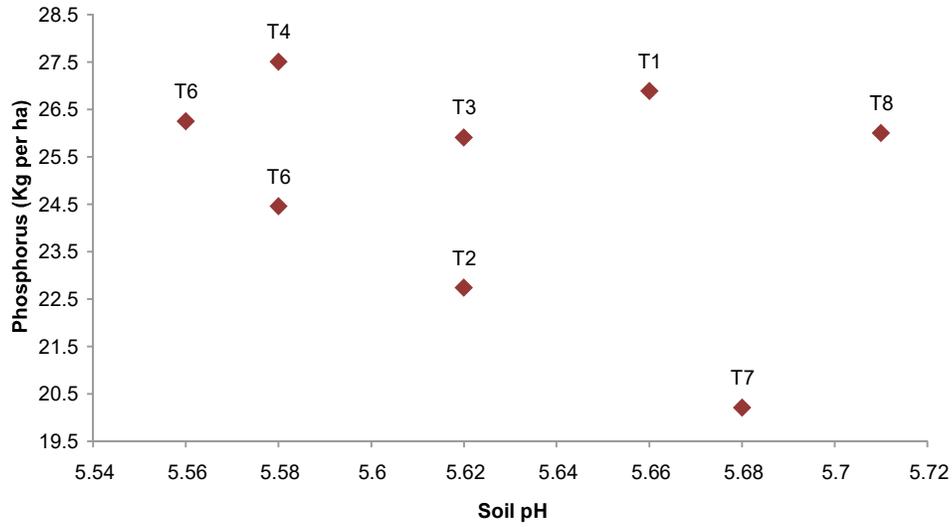


Fig. 1. Trend of nutrient availability: Phosphorus (Kg per ha) with soil pH

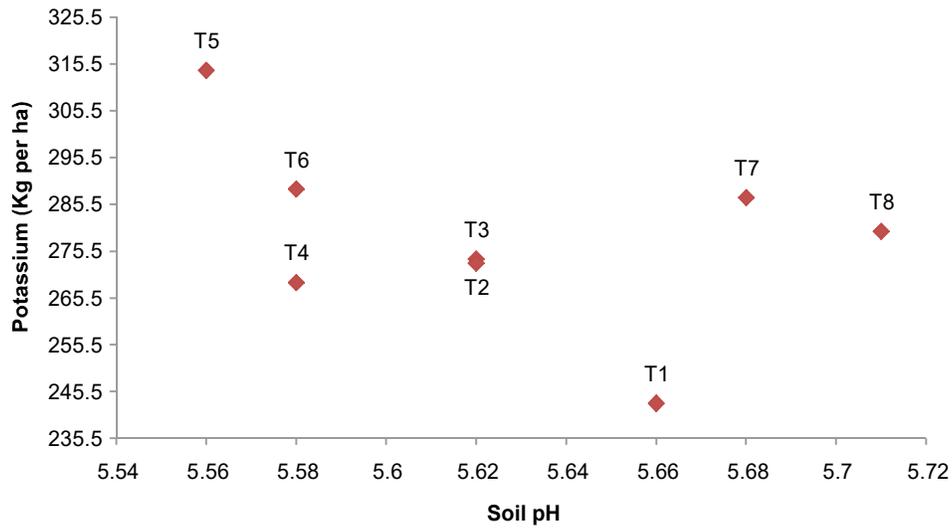


Fig. 2. Trend of nutrient availability: Potassium (Kg per ha) with soil pH

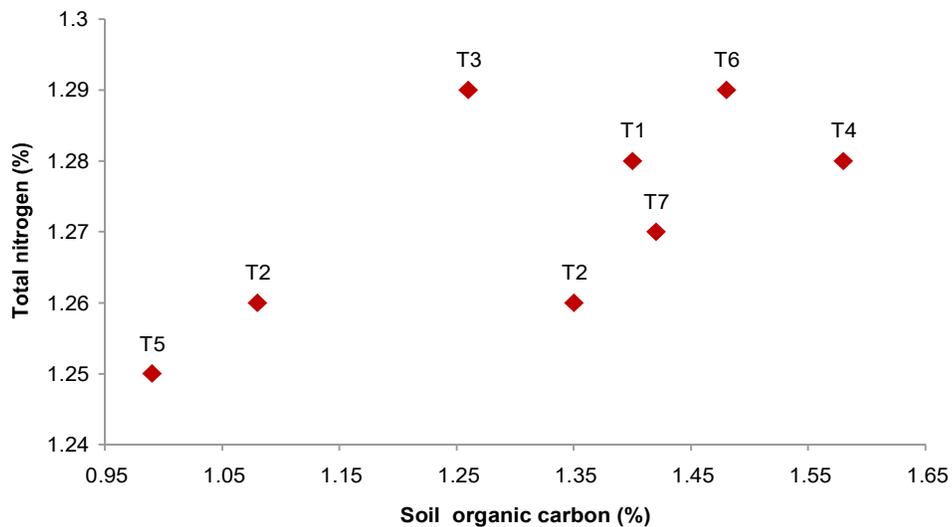


Fig. 3. Trend of nutrient availability: Organic carbon (OC%) and available nitrogen

if deficient frequently restricts plant growth. This nutrient comes from the atmosphere (78% N) and soil organic matter instead of being a constituent of minerals (rocks). Even with high dosages of N fertiliser, most plants acquire 50 to 80% of their N requirement from the soil, making soil their primary source of N. Wibowo and Kasno (2021) reported that the organic carbon and total nitrogen were strongly correlated. Tomar and Bhat (2023) recorded that nitrogen has a significant and positive correlation with organic carbon. The significant relationship between nitrogen and organic carbon, phosphorus, and potassium is similar to the findings reported by Dinesh et al. (2020).

There was no specific type of trend between available phosphorus and organic carbon (Fig. 4). There was a higher

amount of available phosphorus on both sides, i.e., the lower side of OC% and the higher side of OC%. Higher amounts of available phosphorus at higher organic carbon (T4: 27.51 kg per ha @ 1.58%; T1: 26.89 kg per ha @ 1.40%) and higher amounts of available phosphorus at lower organic carbon (T5: 26.25 kg per ha @ 0.95%). Lower amounts of available phosphorus at higher organic carbon (T7: 20.21 kg per ha @ 1.40%; T6: 24.45 kg per ha @ 1.48%). There was no specific trend between available potassium and organic carbon. Among the treatments, there was a higher amount of available potassium on both sides, i.e., the lower side of OC% and the higher side of OC%. Higher amounts of available potassium at higher organic carbon (T7: 286.91 kg per ha. @ 1.42% of OC) and higher amounts of available

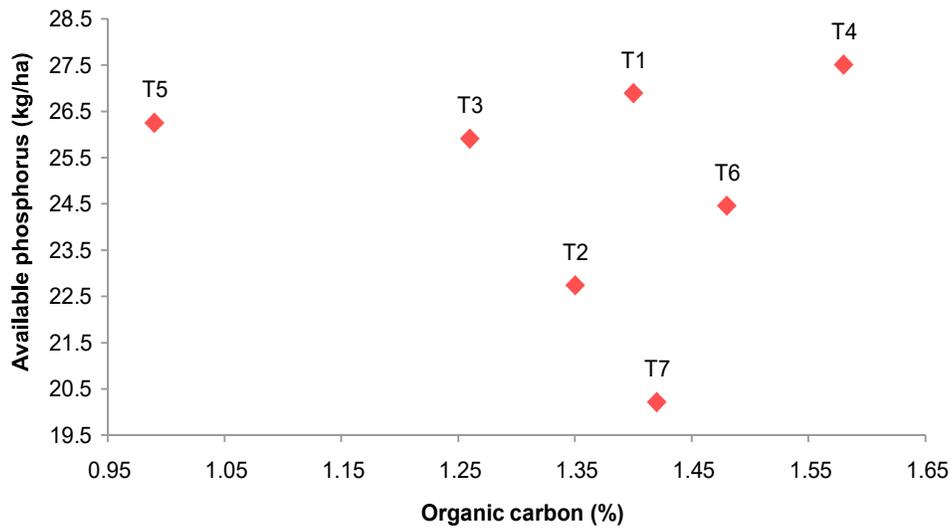


Fig. 4. Trend of nutrient availability: Organic carbon (OC%)and available phosphorus (P)

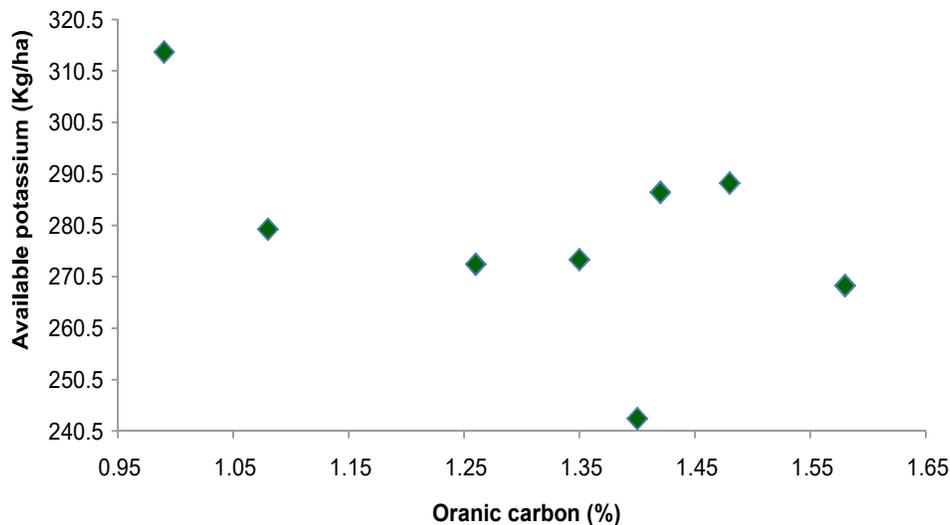


Fig. 5. Trend of nutrient availability Organic carbon (OC%) and available potassium (K)

potassium at lower organic carbon (T5: 314.16 kg per ha @ 0.99%). Lower amount of available potassium was found at higher organic carbon (T1: 242.95 kg per ha @ 1.40% of OC).

Different treatments did not significantly influence the total nitrogen percentage. The T6 treatment recorded the highest total nitrogen percentage (1.29%), followed by T3, T7, and T2, while the T5 treatment recorded the lowest total nitrogen percentage (1.25%). Soils that are too acidic can lower the activity of microbes, which can slow down the breakdown of organic matter and the release of nitrogen from organic sources. This can lead to lower nitrogen availability for plants. Vaidya et al. (2016) observed that control treatments had less total nitrogen than the conservation pit, ring basin, and half-ring basin types of moisture conservation measures. The graded stone bund, stone faced soil bund and soil bund, level soil bund and stone bund improved total nitrogen in the soil (Abay et al., 2016, Worku 2017).

Available phosphorus: Among the different soil treatments, the maximum (27.51 kg per ha) available phosphorus was recorded in T4, followed by T1, T5 and T8 (Table 2). The trend of available phosphorus among the different SMC treatments was $T7 < T2 < T6 < T3 < T8 < T5 < T1 < T4$. Rathod et al. (2020) also observed similar trends where phosphorus ranged from 12.90 to 17.84 kg/ha in temperate forest areas. Phosphorus loss is more frequently associated with erosion and runoff. Eroded sediment carried away bound phosphorus to soil particles (Jeschke 2017). Vaidya et al. (2016) reported higher available phosphorus in the different moisture conservation measures, such as conservation pits, ring basins, and half-ring basins, than in control treatments. The stone faced soil bund and soil bund, terraces, and lands treated with *Sesbania* and elephant grass improved available phosphorus in the soil (Tadele et al., 2013, Worku 2017, Tamrat et al., 2018).

Available potassium: The T5 treatment had the highest available potassium (314.16 kg per ha), followed by T6, T7, and T8. The trend of available potassium among the different SMC treatments was $T1 < T4 < T3 < T2 < T8 < T7 < T6 < T5$ in increasing order. Rathod et al. (2020) also showed a similar trend, with the potassium value ranging from 208.95 to 601.55 kg per ha. In acidic soils, phosphorus can bind to iron, aluminum, and other minerals, forming insoluble compounds. This phenomenon is known as phosphate fixation. These insoluble compounds are not easily taken up by plants and thus reduce the availability of phosphorus. Vaidya et al. (2016) reported higher available potassium in the different moisture conservation measures, such as conservation pit (ha), ring basin, and half ring basin, than in control treatments. The results of stone faced soil

bund and soil bund were improved with higher available potassium in the soil (Worku 2017). Yonas et al. (2017) observed that the effectiveness of soil and water conservation significantly improved potassium than in the control SWC treatment.

CONCLUSION

The study concluded that low-cost in-situ soil moisture conservation measures within chir pine forests had significant impacts on organic carbon, electrical conductivity, soil properties, and nutrient availability. These simple and cost-effective soil moisture conservation practices significantly improve soil properties and nutrient availability. The higher values of organic carbon indicated higher amounts of organic matter in all treatment comparisons, except for the pine needle bund (T5) treatment. These practices improve soil structure, soil moisture, water-holding capacity and enhance organic carbon. This leads to enhanced nutrient availability in the soil through organic matter decomposition, which releases nitrogen, phosphorus, and potassium into the soil in forms that become available to plants over time. Additionally, the specific conservation practices used and their interactions with local soil and climate conditions will play a significant role in determining the outcomes. The findings underscore the importance of integrating such practices into forest management strategies, particularly in water-scarce regions, to ensure sustainable forest productivity and resilience. Further research could explore the long-term impacts and scalability of these measures across different forest ecosystems.

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AUTHOR'S CONTRIBUTION

RD: Conceptualization, write the original draft; Data curation, Investigation, Methodology, Formal analysis, Validation; Visualization **DK:** Conceptualization, Supervision, Writing – review & editing, Funding acquisition, Methodology, Validation; **PK:** Conceptualization, Supervision, Writing – review & editing, Methodology

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