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Relationship Between Fine Root Biomass and Soil Physico-chemical Properties of Grassland Ecosystem in Bhadrapur Municipality of Jhapa district, Eastern Nepal

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Abstract

This study investigated the distribution of fine root biomass and various soil properties in a grassland ecosystem within Bhadrapur Municipality, Nepal. Soil samples were systematically collected from randomly selected blocks in undisturbed, disturbed, and roadside areas during the late rainy season. Analyses included soil texture, moisture content, temperature, pH, and quantification of fine root biomass (FRB; <5 mm diameter) within the top 15 cm soil depth. Results showed the mean FRB was significantly higher in undisturbed areas (7.77 t/ha) compared to disturbed (7.053 t/ha) and roadside (1.76 t/ha) areas. Across all sites, FRB exhibited a positive correlation with soil moisture content. Soil pH was slightly more acidic in undisturbed versus disturbed and roadside areas. Soil temperature demonstrated a positive correlation with FRB in undisturbed and roadside areas but a negative correlation in disturbed areas. Additionally, FRB negatively correlated with sand content in disturbed and roadside areas. The findings highlight how soil moisture is a key driver of fine root proliferation in this grassland ecosystem. Variations in soil texture, pH, and temperature between sites reveal their influence on root growth dynamics. Understanding these root-soil interactions has implications for sustainable grassland management, biodiversity conservation, and ecosystem resilience under changing environmental conditions.

Keywords: Fine root biomass, soil properties, grassland ecosystem, root growth dynamics.

Introduction

Natural grasslands are a complex ecosystem which once occupied at least one-third of the land surface of the earth (Olson & Dinerstein, 1998). White et al. (2000) discovered that most Carbon and Nitrogen reserves are situated underground. Additionally, management practices like fertilization, mowing, and grazing in grasslands can impact plant community composition, litter deposition, and soil characteristics (Hobbie, 2005; Semmartin et al., 2008).

Fine roots i.e., ≤ 5mm in diameter (Vogt et al., 1995), are non-woody and their associated mycorrhizae, are important for the water and nutrient uptake of trees (Finér et al., 2011). They are short-lived, contributing to belowground C fluxes accounting up to 75% of the annual net primary production in the forest ecosystem (Fogel, 1983; Keyes & Grier, 1981). When dead, fine roots are large carbon and nutrient sources and are an important component of forest ecosystems (Nadelhoffer et al., 1985).

Majority of the fine roots are in the surface soil layer (0-15cm). A global survey of temperate grasslands found that belowground biomass averaged 1400 g m^{-2} and that 83% of roots occur in the top 30 cm of soil (Jackson et al., 1997). Grassland root biomass has been reported to outdo aboveground standing biomass by factors of between 2 and 30 (Huang et al., 1988). Prolonged grazing and mowing activities can affect root decomposition processes in two ways. Firstly, through direct mechanisms like altering the composition of plant species and soil decomposer communities (Bardgett et al., 1998). Secondly, indirectly by influencing soil properties such as bulk density and moisture content due to the compaction caused by trampling (Sankaran & Augustine, 2004).

Fine root growth is intricately shaped by altitude, soil chemical properties, and various environmental factors (Chang et al., 2012). Favorable soil water conditions typically coincide with increased new root production, whereas dry periods are associated with a decline in root dry mass (Hayes & Seastedt, 1987). The distribution of roots and water is heavily reliant on soil characteristics, encompassing texture, porosity, and hydraulic conductivity (Bréda et al., 1995). Notably, regions with pronounced soil texture contrasts between topsoil and subsoil experience notable effects on soil hydrology and plant growth conditions (Chittleborough, 1992).

Sandy soils in tropical forests often exhibit heightened fine root biomass due to increased carbon allocation for nutrient and water absorption (Cuevas & Medina, 1988). Regarding Fagus sylvatica, Leuschner et al. (2004) assert that variations in soil acidity and fertility minimally impact fine root system size and morphology but do influence overall root structure and likely contribute to variations in fine root mortality.

Evidence also suggests a positive correlation between soil temperature and root growth, assuming other growth-related resources are not limiting (Pregitzer et al., 2000). Studies in high latitudes propose that root growth dynamics may not directly respond to minor changes in air temperature (D'Imperio et al., 2018). In wet sedge tundra, positive trends in root growth were associated with nutrient availability (Hill & Henry, 2011) and the allocation of photosynthate from aboveground sources, responding to increased surface air temperature. Yet, for certain arctic sedge species accustomed to cold soil temperatures, the primary driver of root elongation was identified as the length of the photoperiod, rather than air temperature (Shaver & Billings, 1977).

Fine roots exert a significant influence on the dynamics of soil organic matter and nutrient cycling processes (Hendricks et al., 2006) and also serve as crucial sources of detritus, playing a vital role in sustaining biological activity within the soil (Pollierer et al., 2007). The input of carbon and nutrients to the soil from fine roots is comparable or even surpasses the contribution made by litterfall, which recycles carbon and nutrients from the canopy back into the soil (Hendrick & Pregitzer, 1993). The biomass, production levels, and turnover rates of fine roots can exhibit substantial variations across different locations, fluctuating significantly throughout the seasons or from one year to the next (Barbhuiya et al., 2012).

Understanding the physical and chemical characteristics of soil, along with its global distribution, is crucial for effective land utilization (Feizizadeh et al., 2013). The rising need for increased food production, driven by population growth, has led to significant environmental damage, impacting soil quality and contributing to land degradation (Foley et al., 2005). This has resulted in the deterioration of both the physical and chemical properties of soil, as evidenced by a study conducted by Zeng et al. (2009).

Measuring roots poses a greater challenge than assessing above-ground plant parts due to their subterranean nature. Despite the pivotal role fine roots play in forest ecosystems' biogeochemical processes (Silver et al., 2005), a notable data gap exists, particularly in tropical regions. This gap stems from methodological complexities in belowground investigations (Vogt et al., 1995), compounded by a lack of consensus on standardized approaches for sampling and calculating root growth across studies. Although fine roots play a vital role, the process of sampling and studying them is laborious and frequently lacks precision, rendering the investigation of fine roots as one of the most demanding yet essential areas of research within terrestrial ecosystem studies. This study focuses on assessing fine root biomass in the grassland ecosystem of Bhadrapur Municipality, Jhapa district, hypothesizing that the high soil moisture levels will correspond to an increase in fine root biomass in the grassland ecosystem.

Materials and Methods

Study area

The present study was conducted in the grassland ecosystem of Bhadrapur Municipality, located in Jhapa district, Southeastern Nepal (Latitude 26^0 32'38.54''N and Longitude 88^0 05'39.70''E). The elevation of the study site is approximately 68 to 113m from the sea level. The sites of Bhadrapur Municipality were selected to collect the soil samples for the estimation of physico-chemical properties of the soil and fine root biomass of road side, disturbed area and undisturbed area.

The climate of the study area is tropical monsoon type. Geographically, Jhapa occupies 1,606 sq.km area of Nepal. Climatic data from 2010- 2019 ranged from 10 to 39.5 °C and the average annual rainfall measured 245 mm (DHM, 2021).

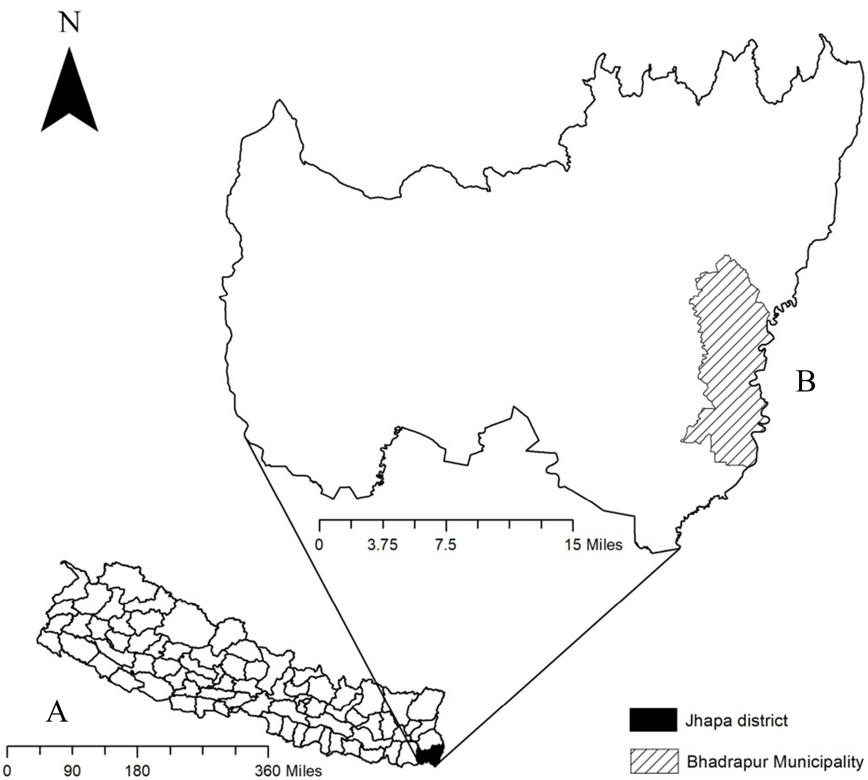


Figure 1: *Map of study area.*

A. Nepal

B. Bhadrapur Municipality within the boundary of Jhapa district

Major plants species observed in the sites were

Digitaria sps, *Ageratum conyzoides, Drymaria* sps, *Imperata Cylindrica, Cyperus* sps, *Eclipta* sps, *Centella asiatica, Cynodon dactylon, Eleusine indica, Commelina* sps, *Paspalum* sps, *Kyllinga* sps and *Mimosa pudica*.

Data Collection

Methods of data collection

Soil samples were collected from randomly selected blocks. At each location soil was excavated from three pits (10cm x 10cm x 15cm), composited and pooled as one replicate. Airtight polythene bags were used for soil moisture to avoid loss of moisture content in the soil. Soil sampling was carried out in September representing the late rainy season. Soil samples were collected from (0-15cm) depth, and all subsequent physico-chemical analyses were carried out at the Laboratory of Mechi Multiple Campus in Bahadrapur. The air-dried samples were sieved through a 2mm mesh screen and used for physicochemical analysis. The determination of soil texture, soil pH, and soil moisture content was performed following the methodology described by Piper in 1966. To determine the soil pH, a glass electrode was employed, utilizing a 1:5 ratio of soil to water in the measurement. Additionally, a soil thermometer was employed to record both soil and air temperatures during the sampling process.

Data analysis

Statistical analysis was performed using MS Excel 2013

Results and Discussion

Data on Fine Root Biomass and soil physico-chemical properties during the late rainy season are presented in table 1, 2 and proportion of sand, slit & clay in different sites of grassland ecosystem of Bhadrapur Municipality are shown in figure 2.

Table 1:

Proportion of Soil and Air temperature of 0-15cm depth in different sites of grassland ecosystem of Bhadrapur Municipality, Jhapa.

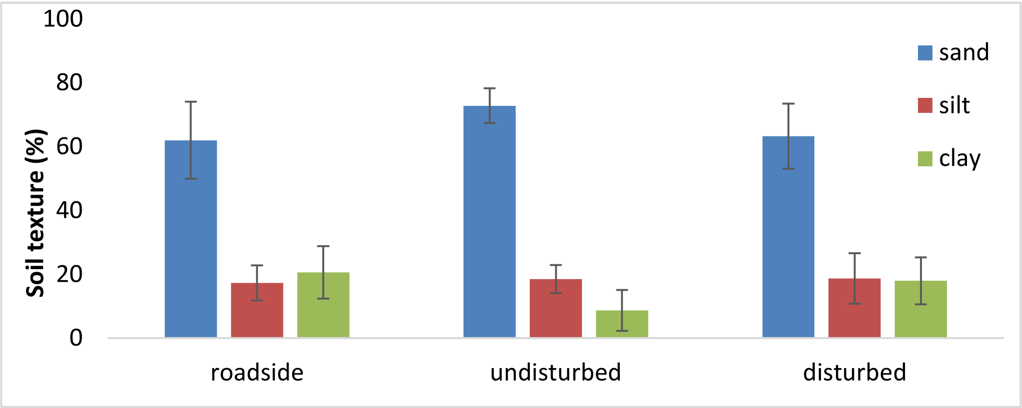
Parameters	Roadside	Undisturbed area	Disturbed area
ST(°C)	30.03±0.48	29.97±0.33	33.77±0.39
AT(°C)	34.23±0.4	35.45±0.25	35.05±0.23

Table 2:

Proportion of soil pH, soil moisture and Fine Root Biomass of 0-15cm depth in different sites of grassland ecosystem of Bhadrapur Municipality,Jhapa.

Parameters	Roadside	Undisturbed area	Disturbed area
Soil pH	6.15±0.08	6.004±0.04	6.28±0.035
SM (%)	27.9±1.92	29.6±2.69	25.5±2.6
FRB (%)	1.76±0.23	7.77±0.69	7.053±0.68

Figure 2:
Proportion of sand, slit and clay of 0-15cm depth in different sites of grassland ecosystem of open area in Bhadrapur Municipality, Jhapa. Bar represents mean values with standard error.



In this study, all examined sites uniformly exhibited a sandy loam soil texture. Soil texture assumes a pivotal role in both vegetation development and nutrient cycling, as elucidated by Robertson and Vitousek (1981). In tropical forests, sandy soils tend to exhibit elevated fine root biomass due to a greater allocation of carbon towards root development, which enhances nutrient and water absorption capacities (Cuevas & Medina, 1988). Notably, the undisturbed area displayed the highest sand content at 72.8% and exhibits higher fine root biomass as compared to other areas, while the disturbed area exhibited the highest silt content at 18.7%, and the roadside area had the highest clay content at 20.6%, particularly in the upper soil depth (refer to Figure 2).

Notably, Hui and Jackson (2006), drawing upon extensive field data, determined that the proportion of belowground net biomass production within total net primary production exhibited a negative correlation with average annual temperature and precipitation. Our results support this notion, demonstrating greater increments in fine root biomass i.e. 7.77% in cooler and moisture (29.97^{0}C) undisturbed areas, in contrast to reduced values of 1.76% observed in drier and warmer (30.03^{0}C) roadside environments.

Evidently, the three areas under investigation displayed marginal variances in atmospheric temperature. The available research on high-latitude regions indicates that subtle shifts in air temperature regimes may not have a direct impact on root growth dynamics (D'Imperio et al., 2018). In the grassland ecosystem, the undisturbed area registered a temperature of 35.45°C, while the roadside and disturbed area recorded a temperature of 34.23°C and 35.05°C respectively (see Table 1).

The acidity of the soil can likewise impede the development of delicate root structures (Persson et al., 1995). Lower soil pH correlates with reduced nutrient mobility in soil solution (Freschet et al., 2017). In this context, lower soil pH in Bhadrapur Municipality may limit nutrient mobility, particularly phosphorus content, in the soil solution. This correlates with Cudlin et al. (2007) meta-analysis, which found that fine root biomass serves as a reliable indicator of soil acidification. Soil pH measurements indicated that the disturbed area had a slightly higher pH value of 6.28, while the roadside and undisturbed area recorded an acidic pH value of 6.15 & 6.004.

Simultaneously, soil moisture (SM) and fine root biomass (FRB) were assessed to understand their intricate dynamics within the ecosystem. Soil water availability emerges as the primary factor influencing changes in root growth strategies (Dowdy et al., 1995) and root mortality during dry periods (Green et al., 2005). Environmental factors, including soil temperature and moisture, which are highly pertinent to climate change, can exert notable effects on fine root biomass (Gimbel et al., 2015). In the roadside terrain, SM was approximately 27.9%, whereas FRB constituted a modest 1.76% of the overall biomass. Conversely, in the undisturbed expanse, SM increased to about 29.6%, with a significantly greater FRB contribution, approximating 7.77%. Meanwhile, the disturbed region exhibited an SM of roughly 25.5%, with a corresponding FRB contribution of approximately 7.053% of the total biomass. This intricate interplay between SM and FRB underscored the nuanced ecological dynamics within these sites.

Relationship between FRB and soil physico-chemical properties

Fine root biomass showed positive correlation with the soil moisture in the roadside, disturbed and undisturbed grass land ecosystem of Bhadrapur Municipality, Jhapa (Table 3, 4 & 5).

Table 3: *Pearson's correlation between FRB and soil physico-chemical properties in roadside area of Bhadrapur Municipality, Jhapa district.*

	Sand	Silt	Clay	ST	AT	Soil pH	SM	FRB
Sand	1							
Silt	-0.830**	1						
Clay	-0.921**	0.550**	1					
ST	0.419*	-0.097**	-0.569**	1				
AT	0.575**	-0.476*	-0.525**	0.613**	1			
Soil pH	0.564**	-0.351*	-0.612**	0.496*	0.431*	1		
SM	-0.693**	0.456*	0.729**	-0.262*	-0.420*	-0.390*	1	
FRB	-0.006*	0.171*	-0.113*	0.177*	-0.071*	0.288*	0.412*	1

** Correlation is significant at the 0.01 level

* Correlation is significant at the 0.05 level

Table 4: *Pearson's correlation between FRB and soil physico-chemical properties in undisturbed area of Bhadrapur Municipality, Jhapa district.*

	Sand	Silt	Clay	ST	AT	Soil PH	SM	FRB
Sand	1							
Silt	-0.169*	1						
Clay	-0.731**	-0.549**	1					
ST	-0.030*	-0.001*	0.026*	1				
AT	-0.245*	-0.461*	0.527**	0.691**	1			
Soil PH	0.304*	-0.307*	-0.045*	0.202*	-0.075*	1		
SM	0.182*	-0.138*	-0.059*	0.274*	-0.224*	0.669**	1	
FRB	0.024*	-0.006*	-0.016*	0.407*	0.124*	0.238*	0.406*	1

** Correlation is significant at the 0.01 level

* Correlation is significant at the 0.05 level

Table 5 :
Pearson's correlation between FRB and soil physicochemical properties in disturbed area of Bhadrapur Municipality, Jhapa district.

	Sand	Silt	Clay	ST	AT	Soil PH	SM	FRB
Sand	1							
Silt	-0.697**	1						
Clay	-0.641**	-0.103*	1					
ST	0.355*	-0.378*	-0.087*	1				
AT	-0.219*	-0.093*	0.404*	0.044*	1			
Soil PH	-0.147*	0.439*	-0.266*	-0.319*	-0.223*	1		
SM	-0.557**	0.681**	0.044*	-0.431*	-0.100*	0.845**	1	
FRB	-0.266*	0.245*	0.107*	-0.687**	-0.141*	0.345*	0.324*	1

** Correlation is significant at the 0.01 level
* Correlation is significant at the 0.05 level
ST = Soil temperature, AT=Air temperature, SM =Soil moisture and FRB=Fine root biomass

Relationship between FRB and soil moisture

The regression relationship between fine root biomass and soil moisture of all the three sites showed that with increase in soil moisture, fine root biomass also increases.

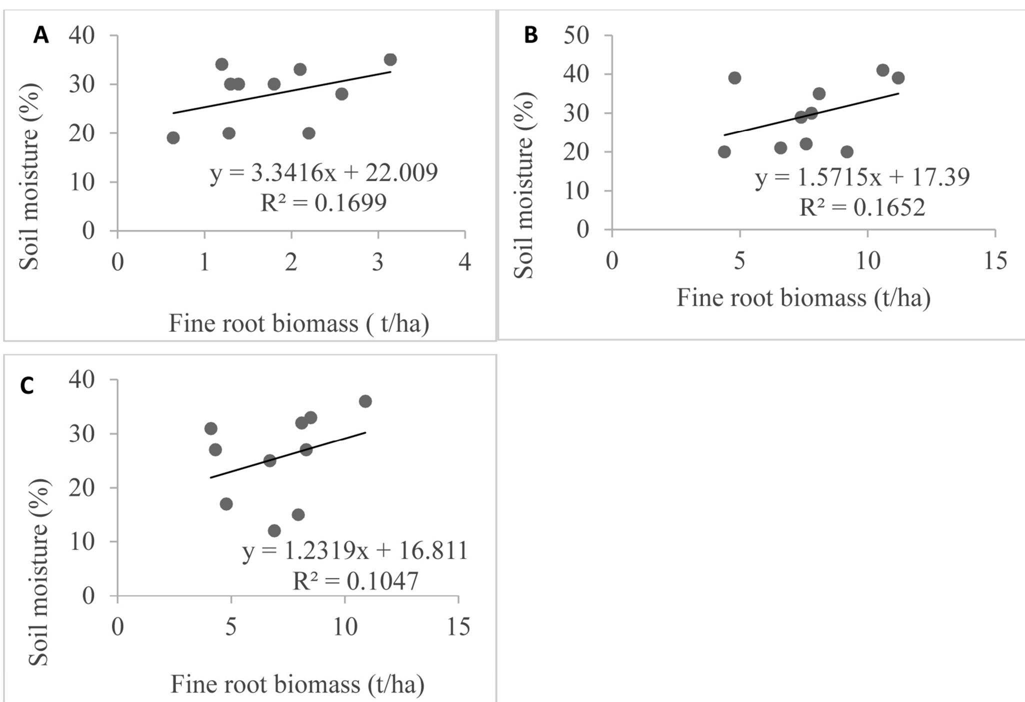


Figure 3:
Relationship between FRB and soil moisture in roadside (A), undisturbed (B) & disturbed (C) grassland ecosystem of Bhadrapur Municipality, Jhapa

Our assumption that fine root biomass is influenced by soil moisture has been substantiated across all studied grassland sites. This verification has been established through regression and correlation analyses, revealing a consistent trend where fine root biomass increases in conjunction with rising soil moisture levels in both undisturbed and disturbed areas.

Soil temperature plays a vital role in regulating both plant and root growth, in addition to influencing nutrient availability (McMichael & Burke, 1998). Yuan et al. (2018) documented a compelling correlation between fine root biomass (FRB) and temperature, highlighting a robust increase in FRB with escalating temperatures supporting our finding in undisturbed area, where a positive correlation (r = 0.407*) was found between FRB and soil temperature.

Studies have reported reduced FRB and/or heightened fine root mortality in heated soils, as observed in research by Wan and colleagues (2004), and Nishar and colleagues (2017), all aligning closely with our observations as a strong negative correlation was observed between FRB and soil temperature (r = -0.687**) in the disturbed sites. However, it's important to note that a recent study conducted on North American forests did not find any evidence of root acclimation to temperature (Burton et al., 2002). Another experiment also indicated that increased soil temperatures are unlikely to have a direct impact on root growth (Edwards et al., 2004).

Our findings suggest weak negative correlation between FRB and sand (r = -0.266) and weak positive correlation between FRB and silt (r = 0.245), FRB & clay (r = 0.107) in disturbed areas. Jones et al. (2010) unveiled the pivotal role of soil texture in shaping root biomass, demonstrating that different soil textures are associated with variations in root distribution and density. In the study done by Świątek et al. (2019) in the nutrient poor sandy soil highest fine root biomass (>1000 g m^{-2}) was observed which is similar with our findings of higher FRB in sandy soil of disturbed and undisturbed area.

Drought conditions have been observed to impede root production, elevate root mortality (Weibhuhn et al., 2011) and consequently reduce overall root biomass, particularly in herbaceous plants (de Vries et al., 2016). Hayes and Seastedt (1987) similarly observed a significant decrease in living roots and an uptick in deceased roots during drought episodes, and these supports our study as a positive correlation between FRB and soil moisture was observed in both undisturbed (r = 0.406*) and disturbed (r = 0.324*) area. In contrast, in the roadside area, even in the absence of water shortage, fine root biomass was significantly lower compared to other sites. We hypothesize that the lower fine-root production in the roadside area, despite ample soil moisture, may be attributed to factors such as nutrient imbalances, soil compaction, pollution, contaminants, microbial activities, competition, and species composition.

In contrast to observations in forests, the alpine grassland experienced an augmentation in root biomass due to soil acidification. This increase was attributed to a rise in the proportion of coarse roots and the generation of fine roots, aligning with boosted sedge and grass biomass, respectively (Wang et al., 2019). Consistent with our observation of increased fine root biomass in the acidic soils of disturbed and undisturbed areas, research on *Fagus sylvatica* (European beech) suggests that variations in soil acidity and fertility have a minimal impact on the size and structure of its fine root system, exerting only a minor influence on fine root morphology (Leuschner et al., 2004). The addition of acidic substances resulted in substantial decreases in soil respiration, fine root biomass, microbial biomass carbon, and microbial biomass nitrogen, with reductions of 14.7%, 19.1%, 9.6%, and 12.1%, respectively (Meng et al., 2019) which aligns closely with our findings in the roadside area where there is decrease in fine root biomass in acidic soil.

In our study, fine root biomass varied significantly among the studied areas during the late rainy season. This variation likely arises from differences in site quality and vegetation species composition. The maximum fine root biomass in both disturbed and undisturbed areas within the upper soil depth during the late rainy season may be attributed to higher nutrient availability, increased clay content, and elevated soil moisture. This is in line with Jenik's (1978) findings in tropical rainforests, where a substantial portion of root biomass was concentrated in the top 0-20 cm soil layer. Similarly, a global review by Jobbagy and Jackson (2000) reported that 70% of root biomass is concentrated in the 0-20 cm increment, consistent with our mean values of 77.7% in the 0-15cm depth of undisturbed areas and 70% in the 0-15cm depth of disturbed areas.

In summary, our study underscores the complex interplay of soil moisture, soil texture, soil pH, soil temperature, and air temperature in shaping fine root biomass dynamics within the grassland ecosystem of Bhadrapur Municipality, Jhapa District. These findings have significant ecological and agricultural implications and contribute to our understanding of root growth responses to changing environmental conditions.

Conclusion

This study elucidated the pivotal role of soil moisture in driving fine root proliferation across undisturbed, disturbed, and roadside grassland areas in Bhadrapur Municipality, Nepal. Undisturbed areas exhibited the highest fine root biomass and soil moisture levels. Soil texture, pH, and temperature influenced root growth dynamics, with higher sand content and slightly acidic conditions favoring root development in undisturbed areas. The findings underscore the significance of maintaining optimal soil conditions, promoting moisture retention, and implementing sustainable management strategies to foster robust fine root systems, contributing to carbon sequestration, water conservation, and overall ecosystem productivity. Further investigations into fine root dynamics can inform site-specific approaches, harmonizing ecological integrity with sustainable land utilization practices.

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