



CHAPTER 5

DISCUSSION



The spatiotemporal variation in C mineralization in soils of the study area recorded is due to the differences in biodegradability of soil organic carbon. The decomposition of soil organic matter relies on soil microorganisms, climatic variables and substrate quality [1] and is effectuated by quantity of C-substrate as it follows first order kinetics. Recorded differences of soil texture among the studied ecosystem influenced the carbon mineralization. Greater clay and silt content in the wetland ecosystem might be responsible for the observed higher CO₂ efflux. Increased clay content attributed to higher soil moisture and total porosity that supported greater microbial growth and activities might result in higher soil respiration rate [2]. Earlier researchers also documented the role of soil texture in regulating carbon mineralization [3, 4, 5]. Greater efficacy of medium textured soil (silt soils) for soil respiration was noted due to better availability of moisture and aeration [6]. Similarly, irrespective of the seasons, the observed higher soil moisture content of wetland ecosystem also supported this hypothesis. Previous studies documented a positive correlation of soil pH with soil CO₂ efflux [7, 8]. However, a negative impact of soil pH on C mineralisation was observed in our study. Wetland soils with lower pH values noted higher C mineralisation than grassland and forestland soils with higher pH values. A plausible explanation could be the higher content of SOC and soil moisture in wetland soil which might obscure the influence of soil pH on C mineralisation. Highest carbon mineralisation value in wetland ecosystem might be due to higher content of soil moisture throughout the seasons that facilitate the substrate diffusion in the soil matrix and help in enhanced microbial metabolism [9]. The results are further corroborated by similar findings of accelerated CO₂ emissions under higher soil moisture content in arid, semi-arid, and floodplain wetlands [10, 11]. Furthermore, extended anaerobic conditions and enhanced reduction of Fe under increased moisture and acidic pH in wetland may promote the mineralisation process of protected C. Following this reduction of Fe, the biochemically labile C are released which subsequently are mineralised as CO₂ and CH₄. Although a substantial portion of soil carbon or dissolved organic carbon (DOC) may remain protected [12], this can possibly negate the kinetic or thermodynamic constraints formerly believed to restrict anaerobic decomposition [13, 14, 15]. However, contradictory results of reduced microbial respiration under soil moisture above an optimum level were observed in previous studies documented [16, 17, 18].

Significant fluctuations of SOC, total N, MBC and enzymatic activities across the ecosystems were confirmed from the results of ANOVA ($p < 0.05$). Higher SOC and total

N content impact soil organic matter by altering the composition and increasing the activity of the soil microbial community [19, 20, 21]. Our finding on higher microbial biomass carbon in wetland ecosystem also supports this. The increase in total N content of wetland soils also imparted corresponding hike in carbon mineralisation by influencing the dynamics of soil organic carbon.

Lack of an epigeal phytomass in the grassland ecosystem redirects all plant-generated carbon into the soil mineral horizons [22]. This increase in SOM input stimulates microbial activity; resulting in increased soil N pools [23]. Thus, the rapid growth and biomass turnover rate of grasses resulted in higher SOC and total N content in the grassland soils. In contrast, the lesser values of SOC and total N in forestland ecosystems could be attributed to a lower decomposition rate of organic matter from dying tree roots compared to decaying grass roots, root debris, slough off tissues and rhizodeposition [24]. Furthermore, limited nitrogen and high C/N ratios of forest soil decrease soil organic matter by hindering the process of decomposition, turnover to microbial biomass, and generation of microbial necromass [25, 26]. Lower values of MBC recorded in the forest ecosystem also supports this.

Higher values of MBC reported in wetland ecosystems of KNP compared to grassland and forestland ecosystem could be attributed to differences in substrate quality and quantity, as well as associated nutrients [27, 28, 29]. Higher soil organic carbon and total N content of wetland ecosystem compared to grassland and forestland ecosystem support this. Zhao *et al.* [30] Yang *et al.* [31] reported similar findings from wetland ecosystems of the Yellow River Delta and Ponyang lake, China, respectively.

Higher activities of the studied soil enzymes in wetland ecosystem compared to grassland and forestland indicate the significant positive influence of waterlogged environment on enzymatic activity [32, 33]. This might be due to pronounced microbial depolymerization of organic compounds under anaerobic environment [34]. Relatively higher activities of carbon cycle-associated enzyme (β - 1,4 glucosidase) from wetland ecosystem might be due to significant positive correlation of the same with SOC. Xiao *et al.* [35] also observed significant correlations between labile soil organic carbon and the enzymatic activities of cellulohydrolase, β -1,4 glucosidase and β -1,4 xylosidase in four characteristic wetlands of Northeast China. Similarly, observed higher activity of N- acetyl glucoaminidase in wetland ecosystem and acid phosphatase activity in both wetland and grassland ecosystem

is due to higher SOC and total N content of the same. This promoted the growth and activity of microbes as it is the primary source of soil enzymes. Similar findings were reported by Ghiloufi and Chaieb, [36]; Ghiloufi et al. [37]; Cenini et al. [38]; Debnath et al. [39]; Piotrowska-Długosz and Wilczewski, [40] in different ecosystems.

Findings of the present study inferred a significant impact of the ecosystems on relative abundance as well as Shannon and Chao1 indices of the soil bacterial communities. *Proteobacteria*, *Chloroflexi*, *Actinobacteria* and *Acidobacteria* were the predominant phyla of the bacterial community across the studied ecosystems. These findings also corroborate previous studies on the composition of soil microbial communities from various ecosystems [41, 42, 43]. The relative abundance of *Proteobacteria* was same across the three ecosystems. Long et al. [44] also reported a higher abundance of *Proteobacteria* in the 5.6–7.8 pH range. Soil pH (5.14-6.90) of the studied ecosystems of KNP also support this. Whereas, observed higher abundance of *Acidobacteria* and *Actinobacteria* followed by *Choloroflexi* in grassland and forestland soils are in consistence with the findings of Acosta-Martinez et al. [45]. They noted higher counts of *Actinobacteria*, soil microbial biomass, and enzyme activities in undisturbed grasslands as compared to crop land. *Acidobacteria* has been reported as one of the commonly found phyla in soil by Zhang et al. [46]. Being a slow-growing bacteria they can thrive in nutrient-depleted conditions like virgin forest soils [47]. Whereas, the greater relative abundance of *Chloroflexi* in wetland ecosystem might be ascribed to the lower pH of wetland soils as compared to grassland and forestland soils. According to Long et al. [44], 33-54% of the total bacterial sequences consist of *Chloroflexi* in low-pH soils. This observation was in line with the findings of Lynn et al. [48], who also reported a higher abundance of *Chloroflexi* in low pH (4.9) soil of southern China.

The key role of the bacterial phyla (*Proteobacteria*, *Actinobacteria* and *Acidobacteria*) in organic matter transformation by cycling soil carbon and thus regulating soil respiration has previously been documented [49, 50, 51]. Thus, the identified important microbial taxonomic groups of this study can plausibly predict the variation in soil respiration across the ecosystems (grassland, forestland, wetland). Correlation analysis revealed a significant positive relationship of *Proteobacteria*, *Chloroflexi* and *Gemmatimonadetes* with soil respiration of the investigated ecosystems. Whereas, the negative association of *Acidobacter*, *Actinobacter* and other remaining identified phylum with soil respiration imply that variation in the soil bacterial community composition could result in a

predictable shift in soil respiration. Thus, observed higher abundance of *Proteobacteria* and *Chloroflexi* in wetland ecosystem also supports the higher cumulative carbon mineralisation in wetland soil. These findings substantiated the recent studies emphasising the importance of microbial community composition in soil respiration [52, 53, 54]. Moreover, soil properties such as pH and SOC have a significant effect on the soil microbial groups and thus indirectly regulate soil respiration rates [52, 55, 56]. The significant positive correlation of soil properties such as pH, soil moisture, SOC, total nitrogen, MBC and soil enzymatic activities with bacterial composition observed in our study also substantiate this. Contrastingly, the lesser evenness and diversity of bacteria as depicted by rarefaction: Shannon and Chao1 curve in wetland ecosystem might be attributed to the prevalence of anaerobic conditions and lower soil pH which is not conducive for bacterial growth. Despite the lower bacterial diversity, the documented higher cumulative C mineralisation in wetland ecosystems might be due to other microorganisms such as fungi that play a significant role in regulating C mineralisation. Similar findings were reported by Xiao et al [57] in a red acidic soil of southwest China.

The presence of phyllosilicates minerals as confirmed from PXRD and SEM-EDX analysis could explain the observed higher SOC content in the studied ecosystems. Earlier researchers [58, 59, 60, 61] have documented the importance of soil mineralogy in SOC stabilization and C sequestration. The observed 2:1 type of clay mineralogy attributed to higher specific surface area (SSA) and cation exchange capacity (CEC) allowing more and/or stronger SOC-clay interactions to facilitate higher C stabilisation [63, 64]. Results of FT-IR spectroscopy confirmed the availability of organic matter in the soil by the presence of polysaccharides, aliphatic and aromatic functional groups. TGA study further confirmed the presence of fulvic and humic acids that comprises the SOM. Irrespective of the ecosystems, the documented stepwise weight loss up to 800°C confirm the presence of recalcitrant SOM. However, statistically non-significant relationship obtained between soil mineralogy and C mineralisation depicts an unclear picture about how and to what extent soil mineralogy affects C mineralization. Moreover, similar spectra observed in XRD and FT-IR analysis in all the ecosystems further confirmed the non-significant role of soil mineralogy on carbon mineralisation. Singh et al. [62] also reported no significant correlation ($p > 0.05$) between soil clay content and C mineralisation.

Higher cumulative carbon mineralisation of wetland ecosystem as compared to the other two ecosystems is supported by the strong positive relationship between SOC content and

carbon mineralisation of the same. However, the calculated lower rate of carbon mineralisation (k) in wetland ecosystem might result in the hike of quality SOC i.e., recalcitrant C-pools in the said ecosystem. Moreover, this increased accretion might also be caused by slow decomposition of organic matter under anaerobic environment of the wetland. Rate and intensity of SOC mineralisation under anaerobic condition is highly influenced by recalcitrance of organic carbon compounds, microbial biomass and availability of electron acceptors [30]. Thus, higher MBC and lower amount of thermally degradable recalcitrant C in wetland ecosystem as confirmed by TGA plot might also possibly explain the increased cumulative carbon mineralisation in the aforesaid ecosystem. Whereas, the higher amount of thermally degradable recalcitrant C in grassland and forestland ecosystems as confirmed by TGA plot might result in the relatively lower cumulative carbon mineralisation in both the ecosystems. However, the recorded lower SOC values of grassland and forestland ecosystems could be due to the higher rate (k) of carbon mineralisation which inhibits the accumulation of carbon in soil.

Seasonal differences of the studied soil parameters across the three ecosystems are likely to be attributed by the variations in air temperature and precipitation which accordingly influence the soil moisture content between the seasons [65, 66]. Higher mean monthly rainfall (242 mm) and temperature (27°C) during monsoon compared to pre-monsoon (mean monthly rainfall of 126 mm and temperature of 25°C) during the study period also supports the documented differences in soil moisture content across the seasons.

Moreover, reported significantly higher C mineralisation in the surface soil of the studied ecosystems compared to the subsurface soil could be related to differences in SOC content and activity of microbes. Furthermore, higher clay contents in topsoil can also be attributed to higher carbon mineralisation, due to greater retention of water [67]. This is in consistent with the findings of Tian et al. [68] who observed significantly higher SOC mineralization rate in topsoil than subsoil in a mid-subtropical zone in China. Earlier researcher also documented decreased microbial activity with soil depth affecting carbon mineralization [69].

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