

Research Article

Soil respiration and its temperature sensitivity to different ecosystems in Annapurna Conservation Area, Nepal

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Abstract

Rising atmospheric CO₂ and temperature are altering ecosystems' carbon cycle. Soil respiration is a potential natural source of atmospheric CO₂, an important terrestrial process to characterize soil as a carbon source or sink. Research carried was out in Annapurna Conservation Area (ACAP) as climate change poses special problems for mountain protected areas. Nepal has targeted to reduce the emissions resulting from land-use change by enhancing forest carbon stock by 5% above the 2015 level within 2025. In this case, identifying, quantifying and addressing different potential emission sources are very important. Soil respiration is the process of measuring natural carbon emissions from soil. The study in ACAP soil carbon emission from the forest, grassland, and agricultural lands was investigated using the close chamber method. The global temperature rise has been set to a global 2°C below the preindustrial period by the IPCC. The rise in temperature has a positive feedback response over soil respiration by increasing CO₂ emission. The study shows the potential simulation of soil CO₂ emission by 0.217 mg m⁻² m⁻¹ in the forest, 0.359 mgm⁻² m⁻¹ in grassland, and 0.457 mg m⁻² m⁻¹ in agricultural land in October in ACAP.

Keywords: Carbon emission, climate sensitivity, ecosystem respiration, soil carbon, temperature rise

Introduction

Atmospheric carbon has been effectively measured and modeled to track the global energy balance and climate change (Millar et al., 2016). Atmospheric carbon dioxide (CO₂) level peaked up to 414.7 ppm in May 2019 (NOAA, 2019). The CO₂ released from natural or anthropogenic sources can abundantly stay in the atmosphere for thousands of years (Lallanilla, 2019). Rising atmospheric CO₂ and temperature are responsible for altering the ecosystems' carbon cycling by giving positive or negative feedbacks to climate (IPCC, 2001). Almost 10% of the atmosphere's CO₂ passes through soils each year (Raich & Potter, 1995). Soil respiration (SR) is one of the major processes of CO₂ emission from the soil (Rastogi et al., 2002). CO₂ is released as a by-product of respiration processes occurring within the soil (Phillips & Nickerson, 2015). All processes occur below the top layer of soil; thus, it is also known as below ground soil respiration (Gupta & Mackenzia, 2016).

Soil respiration is an important terrestrial process in the carbon cycle (Raich & Schlesinger, 1992) as it is the second-largest carbon sink estimated to contribute around 75×10¹⁵ g C per year to the global carbon budget (Schlesinger & Andrews, 2000). Soil is the center of various global issues because it contains 75% of the global terrestrial carbon stock (Eglin et al., 2010). The SR has been widely simulated using

continuous records of temperature (Drobník, 1962), moisture (Hawkes et al., 2017), soil organic matter (Hursh et al., 2016), and many associating elements.

The amount of SR that occurs in an ecosystem is controlled by several factors. Temperature, moisture, nutrient content can produce extremely disparate respiration rates, varying from 10 to 90% depending upon the vegetation type and season of the year (Raich & Tufekciogul, 2000).

The global CO₂ flux in SR demonstrates alteration by different climate (Raich & Schlesinger, 1992), vegetation types (Singh & Gupta, 1977) and plant communities (Ellis, 1974). Vegetation types can define the ecosystem services (Yapp et al., 2010), which are potential determinants of SR rate to modify the responses of soils to environmental change. Seasonal changes in soil microclimate play an important role in defining seasonal differences in soil CO₂ emission within sites, and climatic differences generate different soil respiration rates among distant sites (Raich & Potter, 1995). Ecosystem respiration is the dominant process determining whether a given ecosystem is a net carbon source or sink (Cox et al., 2000). The SR and its rate across ecosystems are extremely important to understand

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because it plays a large role in global carbon and other nutrient cycling (Magnani et al., 2007).

Forest is a large area covered chiefly with trees and undergrowth, which acts as both carbon sink and source. Likewise, grasslands are also one of the world's most widespread natural vegetation. A small variation in carbon storage in grassland soil will greatly affect the concentration of atmospheric carbon and the trend of regional or global climate change (Schlesinger & Andrews, 2000). The amount of carbon during sequestration and emission is not the highest for grasslands compared to a forest, but their large landmass plays an important role in global carbon storage and cycling (Franzluebbers et al., 1994). Over the past 50 years, a huge area of the natural ecosystem has been converted into agricultural ecosystems (Zheng et al., 2006). Organic matter of soil is turned over by a tiling system, which leads to additional greenhouse gas emissions (Climate Central, 2009). According to the report *State of World's Land* by FAO (2011), out of the total 13.2 billion hectares of earth, 28% is covered by forest, 35% by grassland and woodland ecosystem, and 12% by agricultural area. Nepal covers 0.1% of the total global area (Gon/MoFSC, 2014). Out of the total 1,47,181 km² area of Nepal, 45% is covered by forest (MoFSC, 2017), 14% by grassland (Richards et al., 1999), and 29% by agricultural land (World Bank, 2019).

Nepal's GHG-carbon emission is 0.2 tonnes CO₂ per year. Nepal has committed to reducing the emissions resulting from land-use change by enhancing forest carbon stock by 5% above the 2015 level (MoFSC, 2017). About 23% of the total area has been designated for protected areas (DNPWC, 2011). Climate change poses special problems for mountainous protected areas because most of the land areas within their boundaries are at higher elevations (CCME, 2013). Annapurna Conservation Area (ACAP) is one of the protected areas from Nepal at a higher elevation (Tamang, 2010) which seeks high-resolution information from the local and regional scale (Tang & Baldocchi, 2005). Improved understanding of the mechanisms and quantification of the variations in SR in different ecosystems is essential for better managing these potentials because of its high temporal and spatial variations (Tang & Baldocchi, 2005).

Soil respiration has a potential role either to amplify global warming due to its sensitivity to environmental conditions (Cox et al., 2000) or to mitigate climate change by reducing soil carbon sequestration (Dobos, 2003). Paris agreement on climate change recommends limiting global warming to less than 2 °C to avoid the most dangerous effects of climate change, which is likely to involve the removal of CO₂ from the atmosphere (IPCC, 2014). Sequestration of carbon in

soil is a relatively natural way of removing CO₂ from the atmosphere with fewer impacts on land and water, less energy need, and lower costs (Cho, 2018). Thus it could become a tool to mitigate climate change and implement international climate treaties in carbon storage and trading (Luo & Zhou, 2006). This study from the ACAP region is an effort to reflect the soil respiration from the mountainous region of Nepal. Among the variables affecting soil respiration, the temperature is the key to modeling climate change in response in different terrestrial ecosystems (Luo & Zhou, 2006). This research was conducted to study the effect of temperature, moisture, and soil organic carbon in soil CO₂ emission from the forest, grassland, and agricultural ecosystems from ACAP.

Materials and Method

Study area

The ACAP is Nepal's largest conservation area, located in west-central Nepal (Fig. 1). It features an outstanding variety of wildlife habitats and vegetation, stretching from sub-tropical lowlands and lush temperate rhododendron forest in the south to dry alpine steppe in the north. It covers an area of around 7,629 km² (MoFSC, 2015). The study sites were selected along the Annapurna trekking route trail according to the working feasibility, which lies in ward numbers 10 and 11, Annapurna Rural Municipality, Kaski district, Gandaki Province. For mapping of sampling site and study area, ArcGIS software 3.1 was used. Table 1 summarizes the descriptions of study sites.

The study sites were located in the temperate zone (Shrestha, 2008) on the north aspect, dominated by rhododendron forest. This area is much disturbed by human settlement, with trees being looped for different purposes. Major tree species in the study area include *Rhododendron arboreum*, *Quercus lamellosa*, *Q. semecarpifolia*, *Abies spectabilis*, *Acer* sp. and *Mahonia nepaulensis*. According to the report on the status of biodiversity in ACA, 60% mammals, 58% birds, 23% reptiles, 20% amphibians, 53% butterfly and 19% of plant species of Nepal are found in the ACAP region. The studied grassland is a patch of grassland near a settlement area that local people have mainly used as grazing land for domesticated animals such as donkeys, horses, goats, and cattle. The majority of the herbs from the grassland were *Centella asiatica*, *Cynodon dactylon*, *Alternanthera philoxeroides*, and *Oxalis triangularis*. The crops grown in the agricultural land were *Brassica* spp., *Daucus carota*, *Solanum lycopersicum*, *Raphanus sativus*, *Coriandrum sativum*, et cetera. They also grow rice, wheat, millet, and barley on their farm.

Table 1 Ecosystem types and location of study sites

Ecosystem type	Latitude (N)	Longitude (E)	Elevation	Location
Grassland	28°22'13.9"	83°48'18.2"	2160 m	Ghandruk
Forest	28°22'14.9"	83°46'12.0"	2553 m	Tadhapani
Agriculture	28°23'49.2"	83°45'45.1"	2671 m	Tadhapani

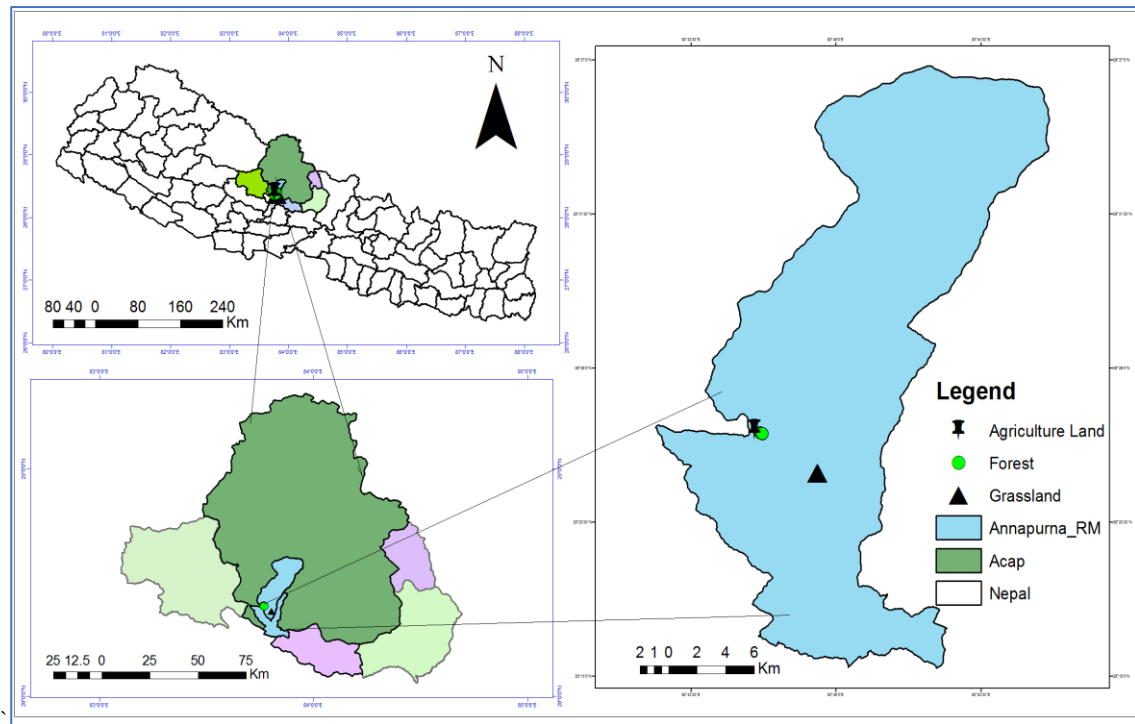


Figure 1 Location of study area showing sampling points for different ecosystem types from ACAP Nepal

The climate varies with altitude and aspect, where 6 °C drops in every 1000 m rise in elevation (DUHE, 1977). The southern monsoon dominates the seasonal climate. Rainfall type is mainly related to an aspect, altitude, and rain shadow effect. The average rainfall ranges from 2,987 mm at Ghandruk, which lies in the cis-Himalayan region (BCDP, 1994).

Data collection

The study was carried out from 27th October to 7th November 2018. Direct measurement of carbon dioxide emission, soil moisture, soil temperature, soil sample collection, and GPS locations were tracked by Garmin etrex GPS. The sample size for the study was ten sampling points (n=10). Secondary data were used from literature reviews, mainly from IPCC reports and temperature data from the Department of Hydrology and Meteorology. A 200 m long transect line of width 50 m. was laid along the trail. Ten chambers were fixed every 20 m distance before 24 hours of study to avoid the disturbance in the specific point of the study.

Measurement of soil CO₂ emission

Soil respiration includes both plant root respiration and microbial respiration through organic matter decomposition. The CO₂ emission measured in the field was total of both root respiration and microbial respiration by using the closed chamber method (Bekku et al., 1995; Koizumi et al., 1999) with an infrared gas analyzer (IRGA). Vaisala CARBOCAP CO₂ probe (Model no.: GMP343) and the cylindrical chambers made of polyvinyl chloride with a diameter of 18 cm and height of 16 cm were used to measure CO₂ (Fig. 2). This method involves placing a closed chamber over the soil surface, and the increase in the

concentration of CO₂ within the chamber is measured as a function of time. IRGA was fitted in the chambers to measure CO₂ and gas temperature. Soil carbon emission was measured one day after the chamber placement on the study point. The soil carbon emission was calculated from the following equation:

$$F = \left(\frac{V}{A} \right) \left(\frac{\Delta C}{\Delta t} \right) \quad (\text{Koizumi et al., 1999})$$

Where, F= Soil respiration (mg CO₂ m⁻² h⁻¹);

V= Volume of air within the chamber (m³);

A= Area of the soil surface within the chamber (m²);

Δc/Δt is the time rate of change of the CO₂ concentration in the air within the chamber (mg CO₂ m⁻² h⁻¹).

Air temperature within the chamber, which was recorded using a temperature data logger, was used to calculate the density of CO₂ within the chamber.

Measurement of soil temperature, soil moisture and sunlight availability

Soil temperature (ST) at 5 cm depth was measured at the time of soil CO₂ emission measurement using the digital lab stem thermometer (Model name: AD-5622, A&D, Japan). Similarly, measurement of soil moisture (SM) was done by using the soil moisture sensor (Model name: Imko, Germany) at 5 cm depth near the chamber (Fig. 2). The soil temperature and moistures were studied only on the 5 cm because the potential soil carbon is released from the top layer of soil. Continuous soil temperature measurement was recorded from the month of soil carbon emission measurements till the date with a Stowaway Tidbit

Temperature Data Logger. Sunlight availability was measured using photosynthetic photon flux density (Ppfd), whose unit is $\mu\text{mol m}^{-2} \text{s}^{-1}$. It was recorded throughout the study period.

Soil sampling and laboratory analysis

The forest carbon measurement guidelines published by the Ministry of Forest and Soil Conservation were adopted for soil sampling (MoFSC, 2017). To determine soil organic carbon (SOC), a corer of 3.5 cm diameter was used. By

clearing the entire residue, the soil samples were collected from three depths (0 – 10 cm, 10 – 20 cm, and 20 – 30 cm), as shown in Fig 3. Five soil samples were collected by the side of chambers fitted for SR from each ecosystem type. From each point, three layers of soil samples were collected, making 15 samples for this study. The number of soil samples could not be exceeded due to its weight and difficulty transporting a large number of soil samples. The SOC was determined in the lab following the Walkley and Black method (Walkley & Black, 1934).

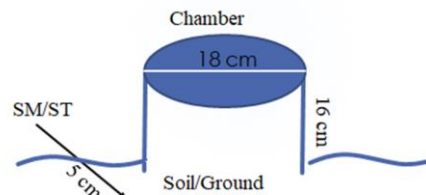


Figure 2 Placing of chamber for soil carbon emission measurement in field

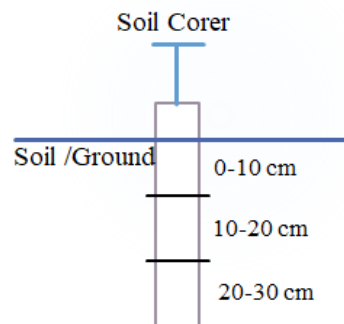


Figure 3 Soil sampling technique used for soil organic carbon

Results and Discussion

Level of soil organic carbon

The mean SOC from different depths in different ecosystems studied is shown in Table 2. The SOC decreased as depth increased in all three ecosystems. Agricultural land had the highest SOC in all three depths, and the forest had the lowest SOC. The values are represented in the box plot (Fig. 4) for clear representation.

Forests and grasslands are natural ecosystems, whereas the agriculture ecosystem is a transformed ecosystem by humans for cultivation. The SOC is lowest in the forest, medium in grassland and highest in agricultural land. The SOC is very high in agricultural land due to cow dung and agricultural residue's continuous addition as waste manure in the top layer, which causes a high deposition of organic matter in the soil. There are a limited number of hotel businesses inside the ACAP region, and all the porters would shelter in these hotels. The porters use donkeys and

horses as means of transportation. The dung from these donkeys and some other domesticated animals are also deposited on the agricultural land daily. Thus, due to the high addition and deposition of nutrients, the carbon content is very high in agricultural lands of ACAP. According to FAO (2017), SOC stock amounts to an estimated $1500 \pm 230 \text{ GtC}$ in the first meter of soil, nearly twice as much as atmospheric carbon, i.e., 828 GtC CO_2 . The soil has been a global net source of GHGs. These processes and emissions are strongly affected by land use, land-use change, vegetation cover and soil management (Fearnside, 2000). SOC stocks in the upper soil layers (0-30 cm) are especially sensitive and responsive to such changes in land use and management (Chiti & Rubio, 2012), which provides an opportunity to influence the amount of CO_2 in the atmosphere. SOM potentially contributes to soil moisture retention and availability and carbon sequestration (Griffin, 2016).

Table 2 SOC in different depths of soil from different ecosystems

Depth (cm)	SOC (%)		
	Forest	Grassland	Agriculture Land
0 to 10	3.96	4.48	9.46
10 to 20	2.35	2.77	6.30
20 to 30	1.35	1.37	1.80

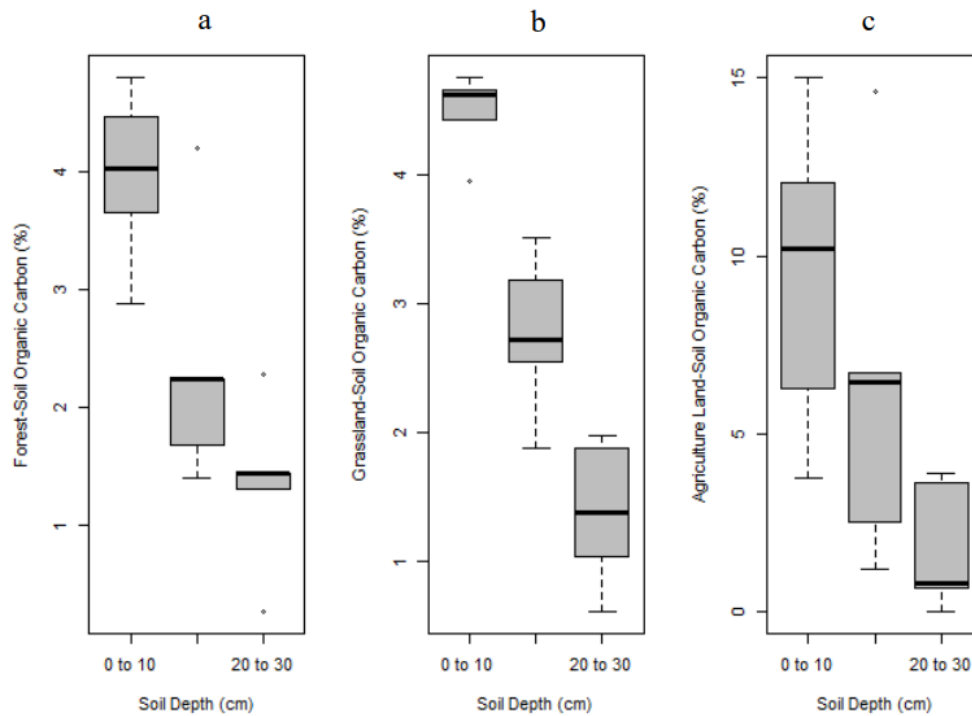


Figure 4 Soil organic carbon variations with depths in different ecosystems where 'a' shows variation in forest, 'b' from grassland and 'c' from agriculture land

Diurnal variation in soil temperature and soil moisture Soil temperature

Soil temperature affects the nutrient dynamics of the soil through fluctuating rate of decomposition of organic matter in the soil (Hood, 2001). It is directly linked with the atmospheric temperature as soil acts as an insulator for heat flow between the solid earth and atmosphere (GLOBE, 2014); thus, different vegetation type and soil cover in different ecosystem types differ in the capability of sunlight to reach the ground and trigger the decomposition process. Temperature variation is less in forests ranging from 5.75 to 7.33 °C. The study was carried out in October, the beginning of the winter season. Leaves turned yellow still canopy was thick due to mixed type of temperate forest with dominating species of *Rhododendron arboreum* and *Acer* sp., which provides continuous shade to the forest by blocking the sunlight and limiting the increase in ST. ST is higher in the daytime when the sun was in its zenith and lowers in the evening time. In the case of grassland (Fig. 5), ST was less in the morning, i.e., 8.26 °C, which increases as the sun rises. ST reaches a maximum in the afternoon and again starts decreasing smoothly with sunset. Likewise, ST is low in the morning time in agricultural land, which is increased rapidly in daytime due to very sparse vegetation and direct exposure of soil to sunlight. ST highly fluctuates in agricultural land from 6.36 °C in the morning to 43.94 °C in the day and decreases to 38.83 °C in the evening.

Soil moisture

The SR rate can fluctuate with the level of moisture content in soil (Ishikura et al., 2016). The SM is high in the forest in the morning and evening time, i.e., 38.83% and 38.67%, respectively, while it is decreased to 32.10% due to an increase in temperature (Fig. 6). In grassland, SM was low in the morning, i.e., 42.41%, as the dew drops are still not melted. It increases in afternoon time up to 48.16% as dewdrops melt through sunlight and flow down to the soil. Due to the evaporation of surface soil moisture, its value decreased to 46.40% in the evening time, and gradually it would balance its moisture level when the sun sets in the evening. SM is 46.03% in agricultural land in the morning. The moisture is high in agricultural land than in forest and grassland because the local people irrigate the land every morning for vegetables that add water to the natural dewdrop. The topsoil in the agricultural land is not as covered as in the forest, so that the moisture would drop with an increase in temperature through sunlight. Exposure of soil to sunlight in the daytime decreased it up to 44% afternoon and 40.03% in the evening time.

The source of water in the soil of the study area is rain or morning dew, snowmelt (NGWA, 2018) or nearby water canals causing groundwater flow and activity of capillary action (Saberian & Jahandari, 2017). Supporting the processes to maintain water balance in soil keeps fluctuating due to soil temperature variation at a different time (Yang, 2019).

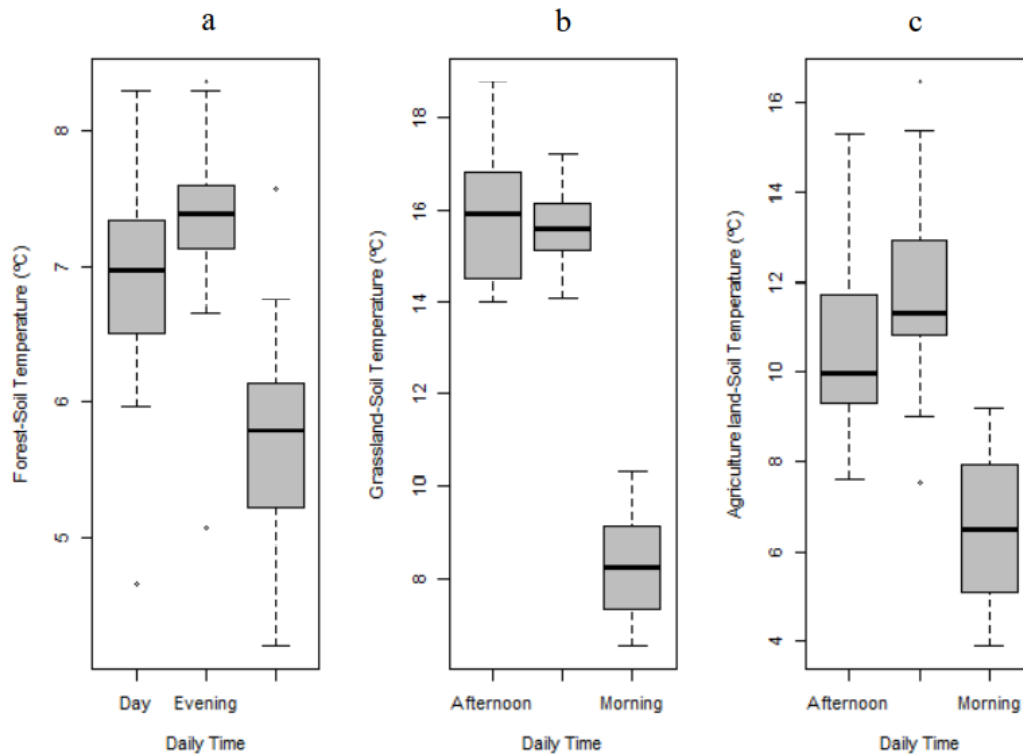


Figure 5 Soil temperature variations in different ecosystems where ‘a’ shows variation in forest, ‘b’ from grassland and ‘c’ from agriculture land

Effect of sunlight availability on soil temperature

Sunlight record from the study period was plotted against soil temperature to show the relation between sunlight and soil temperature (Fig. 7). This relationship is aggregated data from all ecosystems with the motif to generalize the increase in temperature with respect to sunlight availability at its peak time, i.e., at noon, keeping other factors constant. Fig. 7 shows a significant increase in SR with the increase in sunlight availability at the 95% level of significance. Thus, maximum sunlight availability was $1443.66 \mu\text{mol m}^{-2} \text{s}^{-1}$ when ST reached $14.25 \text{ }^\circ\text{C}$. An increase in sunlight availability increases soil temperature, and in the presence of sufficient moisture for decomposition, the respiration process accelerates. The amount of heat from the Sun that reaches the earth is 0.02 cal/m (Borzenkova, 2015). The amount of radiation received by the soil depends on the angles with which the soil faces the Sun (Onwuka & Mang, 2018). Whenever water vapor from soil depths or atmosphere condenses in the soil, its heat increases noticeably (Wang, 2015). Greater the rate of evaporation, the more the soil is cooled (USGS, 2018). Evaporation is based on the amount of sunlight available.

The relation between soil respiration and its variables

Among the factors affecting SOM decomposition, ST and SM are the most relevant. The average ST was detected to be the lowest in the forest, i.e., $8.41 \text{ }^\circ\text{C}$, higher at $11.452 \text{ }^\circ\text{C}$ in agricultural land and the highest at $13.27 \text{ }^\circ\text{C}$ in grassland (Table 3). Forest is a large area covered chiefly with trees and undergrowth, limiting the penetration of sunlight and lowering the atmospheric temperature inside the forest. In agricultural land, ST increases as more soil parts could

directly get exposed to the sunlight in sparse vegetation areas. In ACAP, they maintain distance in vegetable growth and time by time, removal of weed increases the chance of soil to get more sunlight. While in the case of grassland, the vegetation is very low with a high maximum of up to 1 inch as it was starting of the winter season. Thus, the average ST reaches the highest in grassland.

Soil respiration has been widely simulated using continuous records of temperature, moisture, and other variables (Hansen et al., 2000). Moisture is essential for the respiration process, but if the moisture level reaches the saturation level or exceeds, it starts to act as a carbon sink. SM is lowest in the forest, i.e., 32.81%, higher in agricultural land, i.e., 44.93% and highest in grassland, i.e., 45.74%. Moisture is an important variable for predicting organic matter decomposition and soil CO_2 efflux (Fang & Moncrieff, 2001). SOM contains a large carbon reservoir, recently estimated at 1500 PgC (IPCC, 2001), about twice the atmospheric $\text{CO}_2\text{-C}$ pool. Changes in the size of the soil C pool, therefore, can significantly affect atmospheric CO_2 concentrations (Raich & Potter, 1995). As a major flux between atmosphere and land, soil respiration is estimated to be $50\text{--}78 \text{ PgCyr}_1$ (IPCC, 2001), accounting for about 25% of the global carbon dioxide exchange. Therefore, an accurate estimation of soil respiration becomes an important issue in the global carbon cycle. The SOC is the major variable affecting the response of soil in carbon release. Table 3 shows that SOC is the lowest in the forest, i.e., 3.95%, medium in grassland, i.e., 4.48% and maximum in the case of agricultural land, i.e., 7.42%. As the temperature and moisture content of forests are less, the decomposition

of organic matter to organic carbon also gets slow contributing gradual yet less carbon to the soil. While in the case of agricultural land, timely weed clearing and deposition of food waste and animal waste as manure increases the organic matter in the top layer of soil. The organic matter is

high in the top 0-10 cm layer, but due to soil compaction, it is drastically lower down as depth increases. An adequate amount of sunlight, soil temperature and soil moisture accelerate soil respiration in agricultural land (Onkuwa & Mang, 2018).

Table 3 Average values of soil respiration and its variables

Ecosystem	Independent variable (SR)	Dependent variables		
		ST	SM	SOC
Forest	47.94	8.41	32.81	3.95
Grassland	110.94	13.27	45.74	4.48
Agriculture Land	127.14	11.45	44.93	7.42

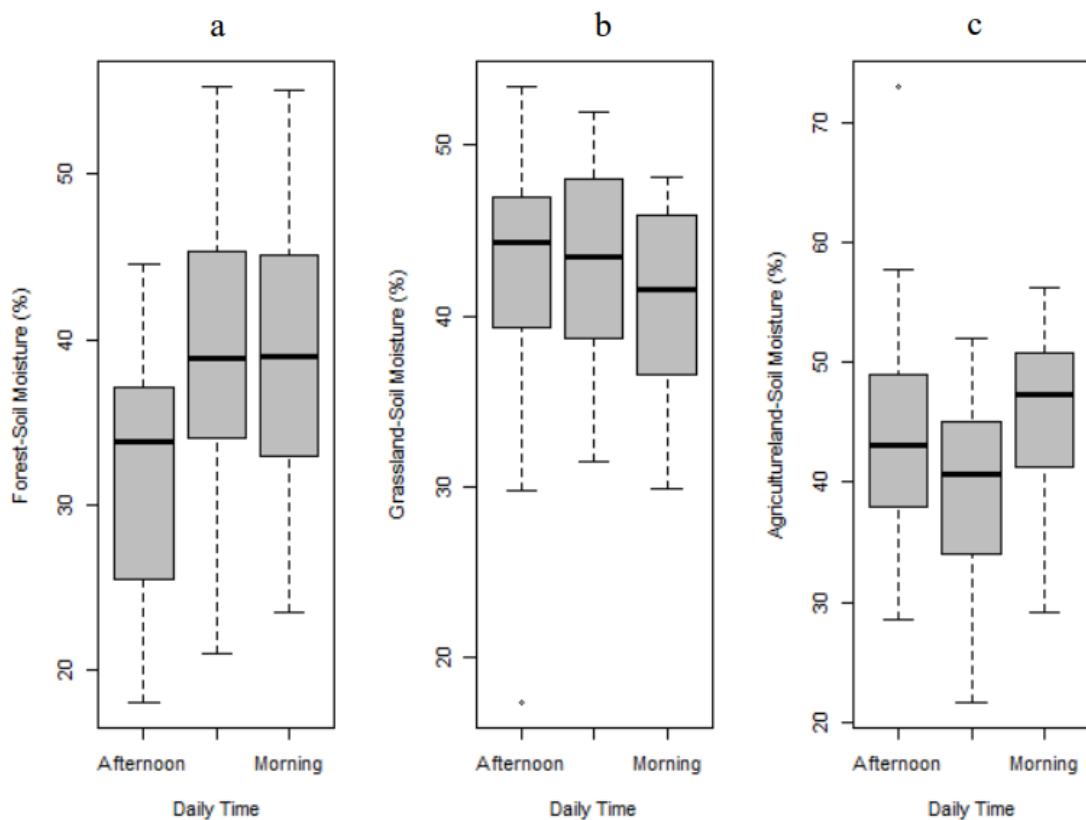


Figure 6 Diurnal variation in soil moisture in different ecosystems where ‘a’ shows variation in forest, ‘b’ from grassland and ‘c’ from agriculture land

Table 4 Relative importance metrics of variables

Variables	Relative Importance Metrics (lmg)
Soil Temperature	0.07
Soil Moisture	0.06
Soil Organic Carbon	0.36

Soil Respiration varies from different ecosystems, which is the result of the effect of its variables. Among three of the studied variables, SOC affects the soil respiration most indicated by the relative importance metrics (Table 4) to be 0.36 lmg, which is highest compared to soil temperature and moisture. After SOC, the soil temperature contributes to the

fluctuation of SR with relative importance metrics value 0.07 lmg and then by the soil moisture 0.06 lmg.

Soil respiration variation in different ecosystems

Different ecosystems have different vegetation patterns, which affects the variables to respond to differently founding variation in soil respiration. Mean forest soil

respiration was found to be $44.49 \text{ mgm}^{-2} \text{ m}^{-1}$, mean grassland soil respiration was $106.06 \text{ mg m}^{-2} \text{ m}^{-1}$ and mean agricultural land soil respiration is $134.75 \text{ mg m}^{-2} \text{ m}^{-1}$ (Fig. 8). SR is highest in agricultural land. Agricultural activities contribute a significant portion (approximately 20%) of global GHG emissions from agricultural soils (Lokupitiya & Paustian, 2006). Agricultural soils can also store atmospheric carbon dioxide into soil organic matter (Onti & Aschulte, 2012). Respiration rates vary significantly among major biome types (Schlesinger, 1977) and side-by-side comparisons of different plant communities frequently demonstrate differences in soil respiration rates (Raich & Tufekciogul, 2000).

Effect of temperature rise on soil respiration

Fig. 9 represents the relation between soil respiration and temperature in different ecosystems. It shows that in the case of forest soil respiration rose by $1.67 \text{ mg m}^{-2} \text{ m}^{-1}$, in the grassland by $2.767 \text{ mg m}^{-2} \text{ m}^{-1}$, and in agriculture land by $3.518 \text{ mg m}^{-2} \text{ m}^{-1}$. Fig. 10 represented the overall increment in soil respiration from ACAP, which is the combination of all three ecosystems. It shows that a $1 \text{ }^\circ\text{C}$ rise in soil temperature would accelerate soil respiration by $12.84 \text{ mg m}^{-2} \text{ m}^{-1}$.

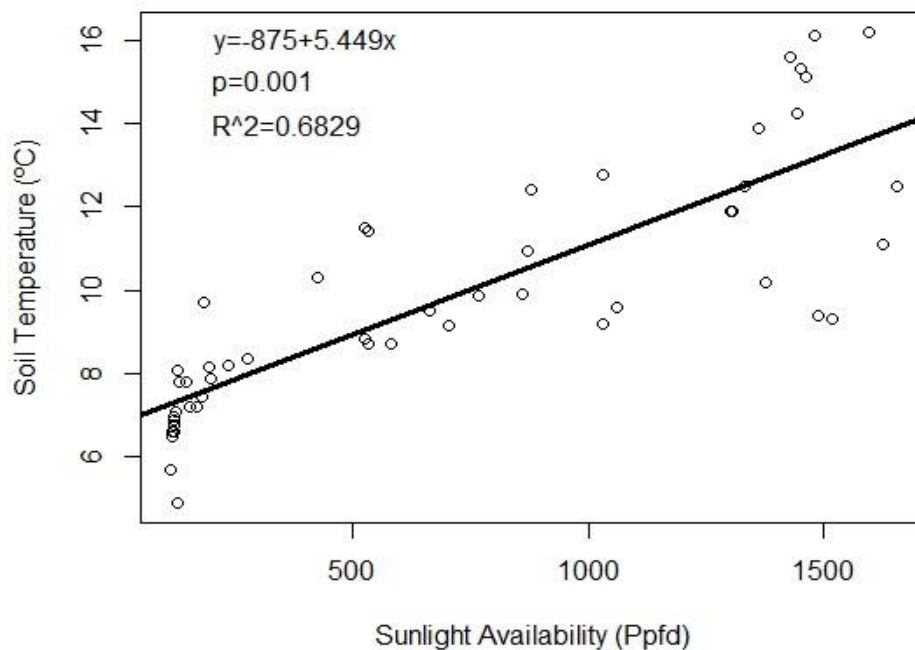


Figure 7 Relation between sunlight availability and soil temperature

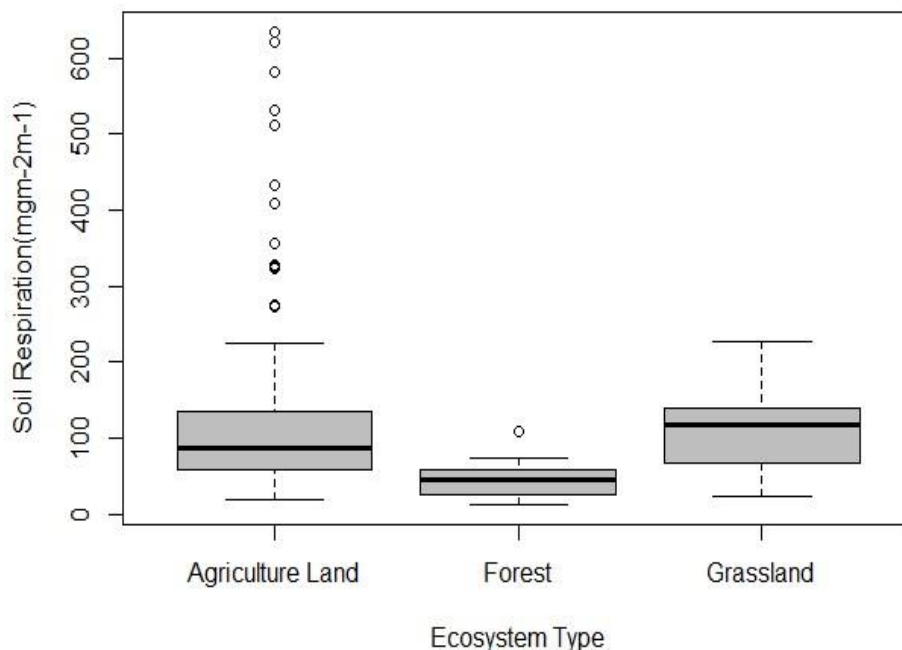


Figure 8 Soil respiration variation in different terrestrial ecosystems

The respiration process in an ecosystem is the dominant process determining whether a given ecosystem is a carbon source or sink (Cox et al., 2000). Rising atmospheric CO₂ and temperature probably alter ecosystem carbon cycling, causing both positive and negative feedback to climate (Norby et al., 1986). A projected rise in temperature for the coming centuries is expected to increase soil temperature and accelerate biogeochemical processes. The biogeochemical flux and stock-related response to warming depend on the physical conditions of soil (Santos et al.,

2019). Temperature is a significant factor in influencing the growth of a biological system (Pepper & Brusseau, 2019). The soil temperature at 0-10 cm is relatively constant with air temperature similar at ambient temperature below 20 °C with $r^2 = 0.3189$ in soil temperature plot against air temperature (Ahmad & Rasul, 2008). Throughout the study period, the average ambient air temperature was 18 °C in ACAP.

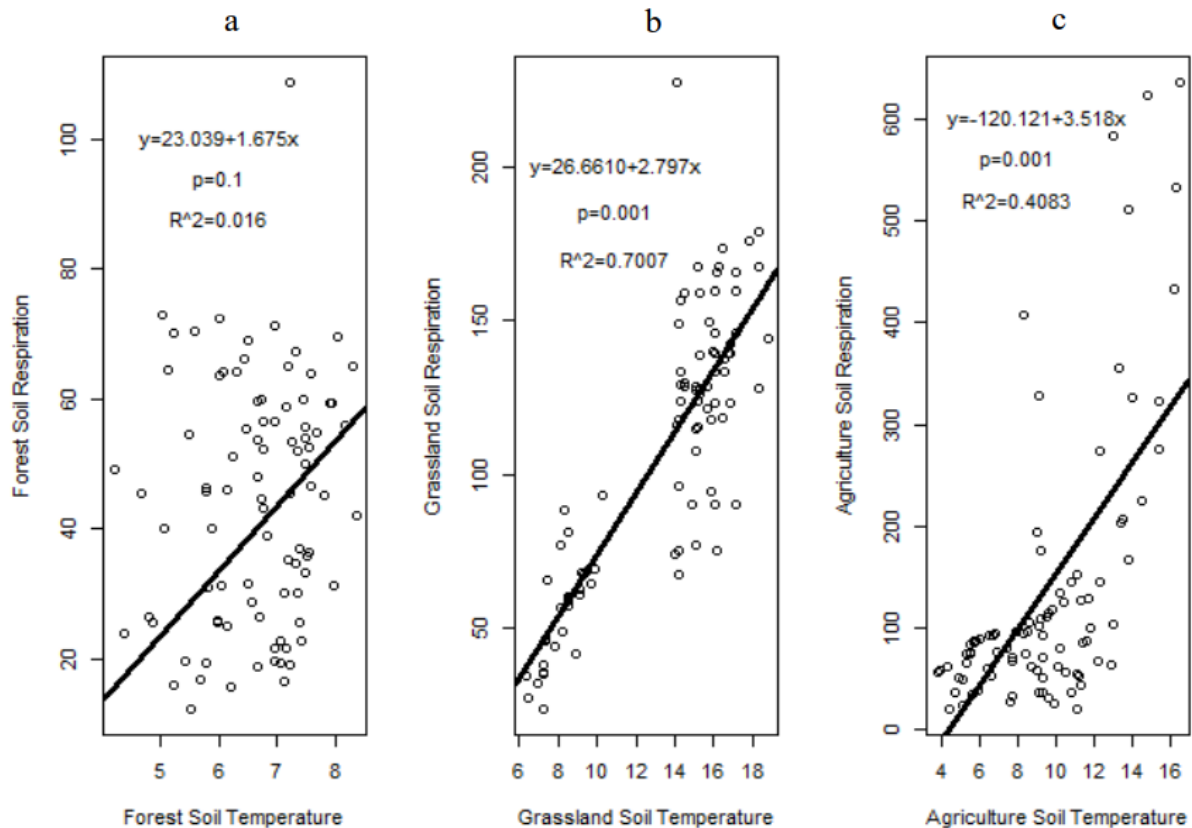


Figure 9 Relation between temperature and soil respiration in different ecosystems where ‘a’ shows variation in forest, ‘b’ from grassland and ‘c’ from agriculture land

Intergovernmental Panel for Climate Change (IPCC) has set the global temperature rise limit to 2 °C in the synthesis report of 2014. So here, let us suppose if the temperature is increased by 2 °C in the future (IPCC, 2014), then based upon the equations above, the SR would accelerate by 3.34 $\text{mgm}^{-2}\text{m}^{-1}$ in the forest, 5.52 $\text{mgm}^{-2}\text{m}^{-1}$ in grassland and 7.0358 $\text{mgm}^{-2}\text{m}^{-1}$ in agricultural land. This increase indicates a 6.98% rise in forest, 4.98% rise in grassland and 5.54% rise in agricultural land. The aggregated SR from ACAP would show the increment by 26.86%, i.e., 25.53 $\text{mgm}^{-2}\text{m}^{-1}$. From 1880-2012 global average temperature has been increased by 0.85 °C (IPCC, 2013). It is the average value in the increase in temperature, which could have a higher effect or lesser effect in regions according to the geographical status. In case of Nepal, from 1971-2014, the average annual temperature has been increased by 0.056 °C (DHM, 2017). Thus, a global rise in 2 °C would increase the temperature in Nepal by 6.5%, which would be 0.13 °C. As a result, if the global temperature is raised by 2 °C then, the SR would be

increased by 0.217 $\text{mg m}^{-2}\text{m}^{-1}$ in the forest ecosystem, 0.359 $\text{mgm}^{-2}\text{m}^{-1}$ in the grassland ecosystem, and 0.457 $\text{mg m}^{-2}\text{m}^{-1}$ in the agricultural ecosystem. Whilst the aggregated effect on ACAP in October would be a 1.664 $\text{mg m}^{-2}\text{m}^{-1}$ rise in soil respiration. The values are very less, which can be sequestered by the thick temperate forest of ACAP. It shows the effect of soil temperature on soil respiration is low in natural ecosystems, forest and grassland, and it shows the significant impact on agricultural land. However, if the effect is projected in the whole ACAP region, then the effect would be higher. It means that even though the effect is less and different in a different ecosystem, the cumulative effect will be higher.

Soil temperature is a significant factor in influencing the growth of a biological system (Pepper & Brusseau, 2019). It is not a standard variable collected from weather stations; rather responds to the net effect of the daily surface energy balance (Waring & Running, 2007); thus, a temperature

measuring instrument like the digital thermometer is used (Yolcubal et al., 2004). Soil texture, color, structure, composition, moisture, the slope of the land, aspect, vegetation cover, season and climate are the factors affecting soil characteristics (Sigdel et al., 2015) that determine its response to global warming. SR can be regulated by controlling soil moisture and temperature to stabilize the soil organic matter (Tulina et al., 2009). Nepal's commitment to reduce the emissions resulting from land-use change by enhancing forest carbon stock by 5% above the 2015 level by 2025 (MoFSC, 2017) can be supported by a comparative study on natural emission from different ecosystem types from Nepal.

The overall research study focuses on climate change and its impact on soil properties that fluctuate the natural soil respiration processes in different ecosystem types found in ACAP. This research work is based on short-term data analysis. For the direct implication of this research in environmental management, long-term (equals to or more than three years) field data collection should be done. Management approaches and mitigation measures can be recommended only based on the long-term data; thus, this type of research should be motivated to conduct on the scale applicable in regional and national management projects.

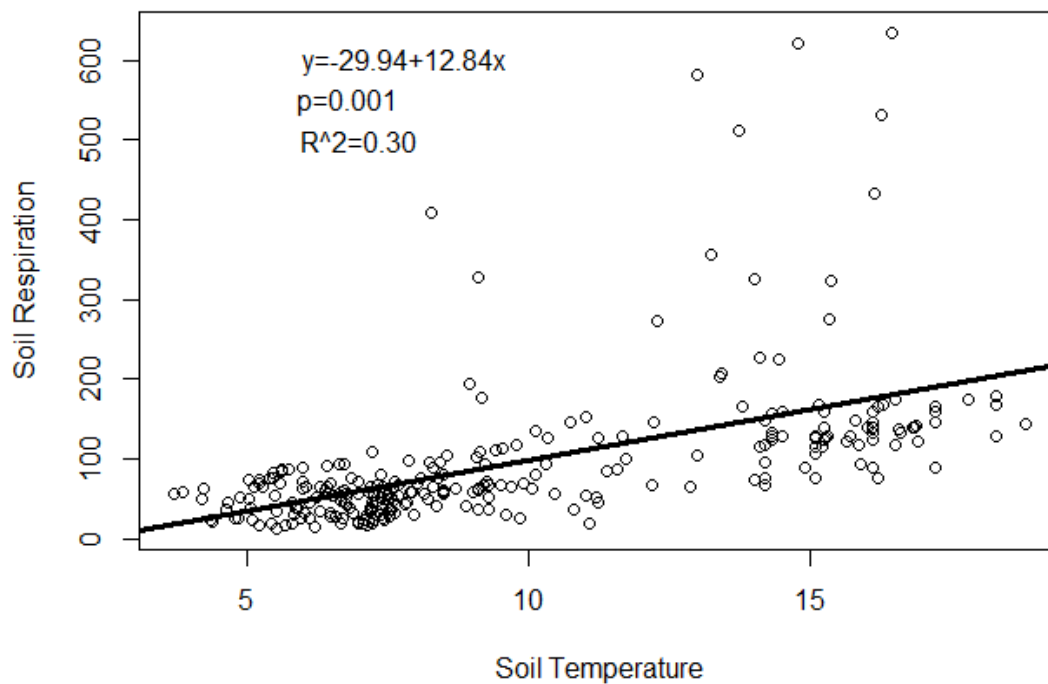


Figure 10 Soil respiration increment in response to soil temperature in ACAP

Conclusion

Soil respiration varies in three of the ecosystems studied in the Annapurna Conservation Area. Soil respiration was found to be highest in agricultural land, followed by grassland and forest. Soil respiration is affected by soil organic matter, soil temperature and soil moisture levels in order of their relative importance. Soil temperature and soil moisture are associated with sunlight availability, which affects the rate of the respiration process. Soil respiration is a highly sensitive process regarding the response to global warming contributing through emitting more carbon dioxide into the atmosphere. Therefore, management of land use is important in mitigating the emission of CO₂ from soil. CO₂ emission was found to be the highest from agricultural land with the highest amount of soil organic carbon necessitating.

Acknowledgements

This work is ostensibly supported by Clean Energy Nepal by providing thesis grant to the first author and ISET-Nepal for providing partial funding for successful completion of the research work and Nepal Academy of Science and Technology for providing the instrumental support.

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