Comparative Soil Organic Carbon Dynamics in Tropical and Subtropical Grassland Ecosystems

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Key Words: Tropical grasslands, Climate Change, Management practices, Grass species

Abstract

Grassland ecosystems play significant role in mitigating the climate change by sequestering atmospheric CO_2. One fifth of the total terrestrial C is stored in the root zone of grasslands as soil organic carbon. However, because of lack of proper management, overgrazing, and conversion to crop lands, these grasslands are becoming a source of CO_2 emissions. It has been observed that in *Imperata* grasslands of Northeast India, a third of total C captured annually is lost though CO_2 emissions. In the absence of intensified grazing and burning, these grasslands exhibit significantly high capacity to store SOC stocks. On the other hand, Southern grasslands of China inherently have a weak C sink. Grazing and burning together significantly increased CO_2 fluxes as observed in Andean grasslands. With the introduction of high yielding grass species and with liberal use of chemical fertilizers, grazing land intensification has been found to rather promote SOC sequestration. It has been observed that in C4 grass species dominated tropical and sub-tropical grasslands; there occurs a rapid transfer of plant C into mineral-dominated C pools. With change of C3 to C4 grass species, the grazer effects rather shift from negative to positive even under decreasing precipitation conditions. Similarly, rise in atmospheric temperatures due to climate change affects grasslands differently depending on the dominating grass species. Graminoids and shrubs appear to benefit from elevated temperatures while forbs are likely to decrease in abundance through competitive elimination. Extreme heat waves and frequent drought events is decreasing the extent and capacity of forests as C sink as compared to grasslands. Grasslands have been shown to be comparatively more resilient to changes in climate. The resilience of grasslands to rising temperatures, drought and fire events helps to preserve sequestered terrestrial C in the root-zone of grassland soil and prevent it from re-entering atmosphere.

Introduction

Grasslands, covering about 40% of total land area around the world, play an important role in animal productivity by contributing about 10% of the total global biomass production. It plays a greater role in mitigating climate change by storing 20-30% of global C in their root zone as soil organic matter (Pasricha 2015). Grasslands, thus greatly help in curtailing the pace and magnitude of global warming and climate change. Carbon stored in the root zone improves soil health, and facilitates storage of moisture in the soil profile (Pasricha 2013; 2015; 2017). On the other hand, adaptive capability of grass species to extreme weather events is more consistent with evolution of new grass species of drought tolerance and adaptation to wild-fire (Dass et al. 2018).Overgrazing on the other hand, results in the depletion of root zone C as CO_2 and act as source rather than sink of CO_2. Land use changes from grasslands to cultivated lands results in release of large scale CO_2 to the environment. With increasing social costs of climate change, managing grassland soils for SOC storage provide great opportunities for environmental and economic sustainability. This paper, high lights the role of grasslands in sequestering C and its storage in the root zone in tropics and subtropics

Material and method

We conducted an analysis of literature to compare the influence of management, grazing intensity, grass species, plant diversity, and temperature on carbon sequestration and structural constitution in the grasslands, Savannas and pastures in tropics and subtropics. Published data was collected from research articles specifically representing regions like *Imprata* grasslands of NE India, *Bundelkand grasslands* of Central India, Western *Garhwal* region of Himalaya, *Leymus chinesis* grasslands of N China, Southern grasslands of China, Neo-tropical Savannas of Brazil, *Cerrado* wet grasslands of Brazil, and Peruvian tropical Mountain grasslands. These biomes are considered an integral part of grassland-ecosystem and play an important role in the terrestrial carbon cycle of tropics and subtropics. The data on the effect of elevated temperatures on the biomass production were used as reported by Buhmann et al. (2016) with the use of "open top chamber "technique.

Results and Discussion

Effect of grazing intensity

Almost 50% of green forage requirement of animals in these countries come from grasslands. However, herbivores have dramatically different effects on SOC, both positive and negative, depending on soil type, precipitation, grass species composition and grazing intensity (GI). GI below the carrying capacity of the systems, results in a decrease in SOC storage, the impact , however, depends on extent of heterogeneity in grass types/species, and variation in the environmental factors of a given site/ regions. At all the GI levels, the SOC stocks increased (+76%) in the moist-warm climate regions, while there was a reduction (-19%) under moist-cool regimes (Abdalla et al., 2018). Under dry-warm and dry-cool climates, only low and low to medium GIs were associated with increased SOC stocks. High GI significantly increased SOC for C4-dominated grasslands compared to C3 and C3+C4 mixed grasslands. Therefore, in order to protect grasslands from degradation, GI and management practices should be optimized according to climate regime and type of grass species. Constantly high GI can ultimately lead to elimination of some less competitive grass species and establishment of other species. High GI may help enhancing C sequestration if the annual average rainfall is low (>60 mm), and this effect may vary with soil type. A linear regression of annual net plant productivity remaining available as a possible OC inputs to the soil, with calculated GI and climate zone (R^2=0.67; $P < 0.001$) demonstrated that SOC stock under moist-cool climatic zone is much higher than in other climatic regimes. It has been observed that composition of grass species and soil conditions in the Tibet pastures was not only affected by GI but also by local environmental factors (Wang et al.2017). Ignoring the regional climate zones, higher GI (below the carrying capacity of the systems), were generally associated with a decrease in SOC stocks.

Effect of grass species and plant diversity

C4-dominated grasslands and Savannas are more common in tropical and subtropical regions. These C4-grasses generally contain higher levels of lignin and cellulose which are generally recalcitrant to decomposition. The extensive above-ground litter produced by C4 species is, however, subject to frequent fire events particularly in years of extended dry-seasons. High GI in dry areas or in C3-dominated grasslands reduces C storage in soil and makes it a more vulnerable to climate change. However, C sequestration in C4 grasslands increases under such conditions. Grazing and fire can have large impact on soil C stocks in C4 grasslands and Savannas (Richie 2014). Management practices that help reduction in fire incidences and resorting to controlled grazing can help restoring the degraded grasslands (Schipper et al. 2007). Accordingly, variables like soil texture, precipitation, grass type, GI, study duration and sampling depth can explain almost 85% of a large variation ($\pm$150 g m^{-2}) in grazing effects. There is significant interaction between soil texture and precipitation; grass type and GI. It was further observed that an increase in mean annual precipitation of 600 mm resulted in a 24% decrease in grazer effect on fine-textured soils, while on light-textured sandy soils, the same increase in precipitation produced 22% increase in grazer effect size on SOC (Richie 2014). Increasing GI increased SOC by 6-7% on C4-dominated and C4+C3 mixed grasslands, but decreased SOC by an average of 18% in C3-dominated grasslands.

Effect of plant diversity or plant community composition also plays an important role in C storage in grasslands. Carbon storage in the soils can be as high as 200% in highest diversity treatment, and 70% greater than monoculture treatment. Higher C storage rates are associated with higher above-ground production and root biomass with presence of C4 multiple grass species in mixture with legumes. Annual storage rates averaged at 88% for 0-60 cm profile, concentration was, however, much higher in the upper 0-30 cm layer. Dramatic increase in C storage with increase in biodiversity after 24 years of growth is shown in Fig.1. Soil C sequestration was positively related to above-ground- and root- biomass.

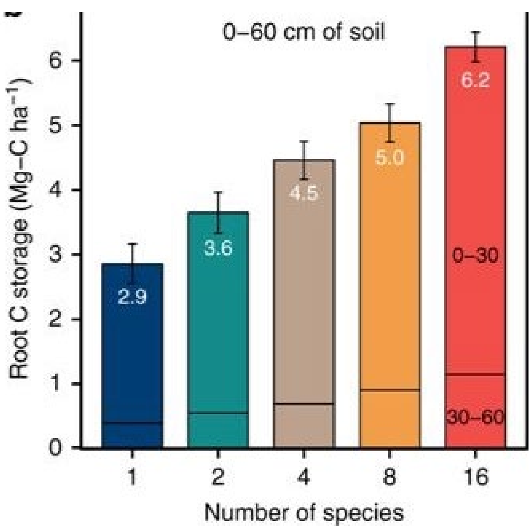

Fig.1. Total root carbon storage in upper 60 cm of soil (Numbers in white indicate mean total root carbon storage And error bars indicate standard errors (Yang et al. 2019).

Effect of increasing atmospheric temperature

A selective effect of increasing atmospheric temperature may result in the elimination of more vulnerable grass species leaving the high temperature tolerant species to ultimately dominate. Global surface temperature has risen by approximately 0.8°C over the last century, and is predicted to increase by 1.4 to 5.8°C during the 21st century (IPCC, 2007). Such rise in temperature may expand the plant growth period, higher fecundity, greater biomass allocation towards below-ground biomass, and possible shift towards tree-dominated biomass. The effect of high temperature will be different depending on whether it is C3- or C4-dominated grassland. Such rise in atmospheric temperatures is reported to have greater impact on tropics and subtropics regions where grass species already occupy a narrow range owing to thermal specialization (Lawrance et al. 2011). Therefore, grasslands in tropics and subtropics are likely to suffer maximum loss in biodiversity with rise in climate temperature. Buhrmann et al. (2016) observed a significant increase in combined graminoid (AGP by ±19.9% per annum) and shrubs above ground productivity with rise in temperature. Below-ground biomass remained unaffected but decreased forbs AGP by ±9% annually.

Forests have always been considered as key ecosystem for C sink; however, with increase in the frequency of extreme heat waves and drought events with rise in temperatures, it is slowly decreasing its extent and capacity as a sink. This is especially so in semi-arid region of the world which constitutes almost 41% of earths land surface. Greater resilience of grasslands to rising atmospheric temperatures, frequent drought and fire events will help sequester and preserve terrestrial C in the root-zone and prevent it from re-entering atmosphere. Effect of elevated temperatures can be successfully investigated in situ using open temperature chambers technique (OCTT). OCTT can further elucidate as to how the elevated temperatures are likely to influence species composition and abundance. This may help evolve better management practices for conservation of tropical and subtropical grasslands and Savannas. Further change in grassland structure with increasing temperatures can be expected due to greater efficiency of C4 species for soil moisture, particularly at low moisture levels. Greater soil moisture deficits in future due to rise in atmospheric temperatures can therefore, make C4 species more successful, further eliminating the low efficient C3 species. This may ultimately lead to the selective elimination of C3 forbs with time. Savannas are the central biome in the transition between grasslands and forests and they are characterized by the co-existence of two types of vegetation, highly shade-intolerant and fire tolerant C4 grass species and C3 trees. C4 grass species can out-compete trees in the driest environment while tree growth is water-limited. This shows that transition between forests, Savannas and grasslands are expected to undergo major changes in future due to climate change and global warming (Baudena et al., 2015).

Conclusion

Grasslands play an important role in mitigating the climate change by storing 20-30% of the total terrestrial carbon in their root zone as organic matter. However poor management and overgrazing in the tropics and subtropics is fast degrading these grasslands. Constant intensive grazing, by decreasing net primary productivity may result in altogether loss of large-leaved grass species giving way to dominance of less palatable narrow-leaved grass species. Plant diversity or plant community composition plays an important role in C storage in grasslands. However, in tropical and subtropical regions, grasslands are likely to suffer maximum loss in biodiversity with rise in climate temperature.

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