Catena 167 (2018) 284–292

Contents lists available at ScienceDirect

Catena

journal homepage: www.elsevier.com/locate/catena

Grassland degradation significantly enhances soil CO_2 emission

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ARTICLE INFO

Keywords:
Grassland management
Soil respiration
Carbon output
Climate change

ABSTRACT

Grassland degradation reduces net primary production and, subsequently, soil fertility and soil organic carbon stocks (SOCs); however, little is known about its impact on soil CO_2 emissions, particularly the emissions relative to SOCs and biomass produced. The main objective of this study, performed in KwaZulu-Natal province of South Africa, was to quantify the impact of grass basal cover, as main indicator of grassland degradation, on soil CO_2 emissions. The soil CO_2 emissions were measured from three grass cover levels (non-degraded, with 100% grass cover; moderately degraded: 25 < grass cover < 50%; and highly degraded: 0 < grass cover < 5%) using a LI-COR 6400XT. The measurements were done at three randomly selected positions in each grass cover level, from January 2013 to April 2015. At each position, measurements were done once during winter months and twice during summer months, resulting in a total of 1053 measurements for the entire study period. The measured average gross soil CO_2 emission was significantly higher (1.78 ± 0.013 g CO_2-C m^{-2} day^{-1}) in non-degraded than moderately (1.60 ± 0.12 g CO_2-C m^{-2} day^{-1}) and highly degraded grasslands (0.68 ± 0.10 g CO_2-C m^{-2} day^{-1}). However, when expressed relative to SOCs and aboveground biomass produced, the trends were opposite. Average soil CO_2 emission relative to SOCs was lowest in the non-degraded grassland (0.034 ± 0.01 g CO_2-C g^{-1}C day^{-1}) and highest in the moderately degraded grassland (0.058 ± 0.02 g CO_2-C g^{-1}C day^{-1}) with the highly degraded grassland being intermediate (0.04 ± 0.00 g CO_2 g^{-1}C day^{-1}). Similarly, soil CO_2 emission relative to aboveground biomass produced was lowest in the non-degraded grassland at 0.15 ± 0.02 kg CO_2-C kg^{-1} biomass $year^{-1}$, which was almost 5 fold lower than 0.73 ± 0.01 kg CO_2-C kg^{-1} biomass $year^{-1}$ in the highly degraded grassland. Gross soil CO_2 emission correlated significantly and positively with SOC (r = 0.83 and 0.82 for SOC content and stocks, respectively), SON (0.67 and 0.53 for content and stocks, respectively), C:N ration (0.62), and soil water content (0.75) but negatively with clay content (−0.89). Soil CO_2 emission relative to SOCs correlated significantly and negatively with both SOC (−0.50 and −0.51 for content and stocks, respectively) and SON (−0.45 and −0.42 for content and stocks, respectively). While gross CO_2 emissions decreased with grassland degradation, CO_2 emission relative to both SOCs and aboveground biomass increased with grassland degradation. These results point to direct links between grassland degradation and global warming because CO_2 is one of the key greenhouse gases. Therefore, strategies for rehabilitating degraded grasslands need to aim at reducing soil CO_2 emission in order to mitigate climate change.

1. Introduction

The increasing atmospheric greenhouse gas concentration, due to anthropogenic disturbances, is a matter of great concern. Grasslands play a crucial role in the global carbon (C) cycle as they cover 40% of the world surface area and store about 10% of the soil C stock of 2400 Pg (1 Pg = 10^{15} g = 1 billion tons) (Suttie et al., 2005). Land degradation, defined as a process which lowers the capability of soils to produce food and fodder (FAO, 1979), is generally attributed to human activities, especially changes in land use and/or land mismanagement (Shang and Long, 2007; Gang et al., 2014; Fassnacht et al., 2015). Approximately 50% of global grasslands are reportedly already degraded (Gang et al., 2014).Grassland degradation, generally regarded a reduction in soil basal cover, has well-known negative consequences on grass production and biodiversity (UNEP, 2007; Dong et al., 2012). The reduction in soil basal cover results in significantly lower soil

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https://doi.org/10.1016/j.catena.2018.05.010
Received 23 May 2017; Received in revised form 10 April 2018; Accepted 10 May 2018

infiltration by water. Reduced infiltration, in turn, induces and soil C erosion (Mchunu and Chaplot, 2012), which reduces soil organic carbon stocks (SOCs) (Dlamini et al., 2014), water content (Yi et al., 2012) and soil temperature (Mills and Fey, 2004).

Several studies have extensively investigated the impact of grassland degradation on SOC stocks (SOCs). For instance, Dlamini et al. (2016) in a meta-analysis of 131 comparative studies worldwide showed that grassland degradation reduces SOCs by an average 9%, with 16 and 8% reductions in dry and wet climates, respectively. Dong et al. (2012) also reported significant decline (33%) of SOC with increasing degradation in the Qinghai-Tibetan Plateau of China. In addition, Dlamini et al. (2014) reported SOCs loss of as much as 89% following degradation of grassland in the sub-tropical climate of South Africa. While these studies and numerous others reported on the impacts of grassland degradation on SOCs, there are very few studies reporting on the consequences on soil CO_2 emissions. For example, Rey et al. (2011) reported 25% higher soil CO_2 emissions from non-degraded than degraded grasslands in Southeastern Spain. Traoré et al. (2015) reported as much as 82% higher soil CO_2 emissions from non-degraded than degraded grasslands in semi-arid West Africa. In contrast, some studies reported more soil CO_2 emissions from degraded than non-degraded grasslands (Cao et al., 2004; Li et al., 2015; Chen et al., 2016). For example, Chen et al. (2016) reported 23.6% more annual CO_2 fluxes from degraded than non-degraded soils. Li et al. (2015) reported similar findings, which they explained to be a result of higher soil temperatures leading to greater C mineralization. The contradicting results on the impact of grassland degradation on soil CO_2 emissions might require further appraisal. Work is also still required to inform on the impacts of grassland degradation on soil CO_2 emission relative to SOCs and biomass production. The CO_2 emission relative to SOCs and biomass produced could serve as indirect means of evaluating SOC stability and the economic use of C by grasslands, respectively, which are further indicators of ecosystem functioning. In addition, knowledge on the factors controlling soil CO_2 emissions following grassland degradation is important during formulation of strategies to minimize soil CO_2 emissions by maximizing soil C protection and/or sequestration, and biomass production. Therefore, the present study performed on a grassland in KwaZulu-Natal, South Africa, aimed to assess soil CO_2 emission as a function of grass basal cover, SOCs, grass production and a series of environmental and soil properties. The study hypothesis was that low basal cover increases soil temperature, which in turn enhances soil C mineralization to yield higher soil CO_2 emission than under non-degraded grasslands.

2. Materials and methods

2.1. Study area

The experiment was conducted at Potshini (29° 21′ E, 28° 48′ S; altitude range 1080–1455 masl), located 10 km south of Bergville town in KwaZulu-Natal province, South Africa. The area experiences a temperate climate characterised by warm wet summers and cool dry winters. The long-term (30 years) mean annual temperature and precipitation of the study area are 13 °C and 684 mm, respectively (Dlamini et al., 2011). Moist Highveld Sourveld dominated the native vegetation of this area (Camp and Hardy, 1999). The experimental site was located on a hillslope of about 10% slope gradient. The site exhibited a grassland degradation gradient where soil basal cover decreased in an upslope direction. Its soils were classified as *Plinthic Acrisols* (WRB, 2006) derived from sandstones and mudstones. More details about the study site characteristics are in Dlamini et al. (2014), Mchunu and Chaplot (2012) and Podwojewski et al. (2011).

2.2. The experimental design

Dlamini et al. (2011) initiated the experiment, in a rural community, with the aim of investigating potential techniques for rehabilitating degraded communal grasslands. An area measuring 1500 m^2 (30 m × 50 m) and showing morphologically, chemically and physically homogeneous soils was demarcated. This area also showed grassland degradation intensities with the downslope position non-degraded (grass aerial cover, of 100%), the mid-slope moderately degraded (25 < grass cover < 50%), while the upslope position was highly degraded (0 < grass cover < 5%) (Mchunu and Chaplot, 2012; Dlamini et al., 2014). The demarcated area was further divided into several upslope-downslope swaths so that each swatch, treated to a specific grassland management technique, covered all three grass cover levels (Dlamini et al., 2011; Mchunu and Chaplot, 2012; Dlamini et al., 2014). The current study measured soil CO_2 emissions from a ring-fenced swath to eliminate any interaction with livestock, fires or any other significant disturbance. The soil CO_2 measurements were performed at three randomly selected positions per grass cover level. A plastic (PVC) collar (diameter = 10 cm, height = 4 cm) was set up at each position. The PVC collars were inserted 2 cm into the soil between grass tufts, two weeks before the first CO_2 emission measurements of to avoid errors associated with soil disturbance (Hui-Mei et al., 2005; Heinemeyer et al., 2011).

2.3. Soil CO_2 emission measurements

The soil CO_2 emission measurements were performed using a LI-COR 6400XT gas analyzer (LI-COR, Lincoln, NE, USA) fitted with a LI-COR 6400-09 soil respiration chamber. The closed chamber system had an internal volume of 991 cm^3 and a surface area of 71.6 cm^2 (Healy et al., 1996). Immediately before CO_2 measurement, the chamber was positioned on the PVC collar. The measurements were performed once a month during dry winters and twice a month in wet summers, from January 2013 to April 2015. Three readings were recorded per measuring position during each measurement session. Thus, 1053 soil CO_2 emission records were generated in 39 days that the experimental site was visited for the purpose of measuring soil CO_2 emissions. On each day, CO_2 measurements were performed between 10.00 and 13.00 h to avoid strong influences of diurnal variations. The CO_2 fluxes, measured by the LI-COR, were converted to CO_2-C based on atomic weights of C and oxygen. The fluxes were subsequently expressed in (i) gross soil CO_2 emission: g CO_2 per unit of surface area (g CO_2-C m^{-2} day^{-1}); (ii) soil CO_2 emission relative to SOCs: g CO_2 per gram of soil C (g CO_2-C g^{-1} C day^{-1}); and (iii) soil CO_2 emission relative to amount of aboveground biomass produced: g CO_2 per kg of aboveground biomass (g CO_2-C kg^{-1} produced biomass $year^{-1}$).

2.4. Soil temperature and soil water content

Topsoil (0–0.05 m) temperature and water content were measured in conjunction with soil CO_2 emissions. Temperature was measured using a thermocouple connected to the LI-COR chamber. Water content was measured using a Hydrosense soil moisture meter (Campbell Scientific, Inc., USA), which was calibrated at the study site. The soil temperature and water content measurements were performed at randomly selected positions within a 0.2 m radius from each PVC collar.

2.5. Soil sampling and analysis

Topsoil (0–0.05 m) samples were collected for evaluating SOC (SOC_C) and soil organic nitrogen (SON_C) contents. Sampling was performed in June 2014. Three replicate samples were collected from randomly selected positions 0.2–1 m from each PVC collar. The samples were first air-dried for 48 h, before gently grinding and sieving them through a 2 mm sieve. The soil particle size distribution was determined on the sieved samples using the pipette method (Gee and Bauder, 1986). Total C and nitrogen content were measured using LECO CNS-2000 Dumas dry matter combustion analyzer (LECO Corp., St. Joseph,