



Carbon exported in runoff from grazed semiarid lands in the Fitzroy Basin, Queensland, Australia

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Abstract

The complexities of nutrient cycling in grazing systems are influenced by management practices and soil characteristics. Grazed land accounts for approximately 71% of the total land area in the Great Barrier Reef (GBR) catchment and plays an important role in soil organic carbon storage and cycling. This study investigates the effect of vegetative ground cover and soil properties on the export of carbon fractions in runoff from grazed land in the Fitzroy and Burdekin Basins of the GBR catchment under simulated rainfall.

Particulate organic carbon (POC) in runoff was driven by fluctuations in ground cover, where POC increased as ground cover declined. Soil type and texture, specifically clay fractionation, also contributed to the export of POC. In contrast, dissolved organic carbon (DOC) exports were independent of ground cover condition and instead linked with soil type; these being Dermosols, Sodosols, and Vertosols. Clay content less than 50% in the parent soil influenced DOC load, especially as an interaction with ground cover. The enrichment of DOC in runoff as clay increased and ground cover decreased suggests soil type, and associated texture properties, facilitate DOC mobilisation, and is enhanced by the disaggregation of soil particles as driven by the erosive action of raindrops and overland flow.

Raindrop impact, runoff, and entrainment of sediment are the primary drivers for POC losses, particularly where ground cover is scarce. However, the presence of DOC in runoff is influenced by the inherent characteristics of the surface soil. Interestingly, the organic matter content of the surface soil had little influence on the carbon fractions in this study. These findings highlight the importance of vegetative management in reducing POC losses from hillslopes through runoff. The lateral movement of soil organic carbon because of depletion in POC and DOC is an important aspect of the terrestrial carbon budget.

Introduction

Soil plays a central role in regulating the global carbon cycle, storing approximately 300 times the equivalent emissions from fossil fuels as soil organic carbon (Schulze and Freibauer 2005). As the largest terrestrial carbon pool, soil contains up to three times more carbon than the atmosphere and vegetation, making it a critical component of climate regulation and ecosystem functioning (Jobbágy and Jackson 2000;

Lal 2003). Research has discovered that agricultural practices have caused a decline of organic carbon from terrestrial systems (Kirschbaum et al. 2008; Thornton and Shrestha 2021). Organic carbon is an integral component of soil fertility and marine ecosystems, and understanding its fate through the hydrological cycle is receiving attention in research (Lal 2005; Berhe et al. 2007; Garzon-Garcia et al. 2015; Burrows et al. 2023).

Coastal waters of the GBR, Australia, showed an increasing trend of POC and DOC over a twelve-year period from 2005 to 2017 (Lønborg C. 2016; Waterhouse et al. 2018). Thornton and Elledge (2022) observed that heavy grazing pressure significantly increased the amount of runoff above that attributed solely to land use change, thus increasing the amount of sediment (including POC and DOC) being exported. The erosion of fine sediment is well documented from grazing lands and is associated with carbon both in runoff and as a component of declining soil fertility (Thornton and Shrestha 2021; Elledge and Thornton 2022; Thornton 2022).

End of catchment sediment loads are exacerbated by runoff and erosion processes, and contribute significant nutrients, including carbon, to stream systems and the marine environment (Ludwig et al. 1996; Bianchi 2011; Garzon-Garcia et al. 2015; Bainbridge et al. 2018). Greater understanding of terrestrially generated organic carbon loads will help quantify exports to the GBR (Lønborg C. 2016; Nachimuthu and Hulugalle 2016; Bainbridge et al. 2018), especially considering grazing is a significant portion of land use in the GBR catchment (71%). This study documents the mobilisation of POC and DOC in runoff from plot-scale rainfall simulation trials on grazing land in two GBR catchments.

Methods

The soil types included in this investigation are classified as Dermosols, Sodosols, and Vertosols, and represent 67% and 19% of the soils found in the Fitzroy and Burdekin Basins under grazing, respectively. The Fitzroy and Burdekin are the two largest basins in the GBR catchment, which combined, represent 70% of the total catchment area. Data was collected *in situ* on hydrologically bunded plots for each soil type under simulated rainfall with various ground cover conditions. Rainfall intensity applied averaged 81 mm/hr across 89 plots. Runoff from these sample plots (1.7 to 3 m²) was collected from a galvanised flume draining into a connection pipe. Sample collection, water quality and soil chemical analysis methods are outlined in detail in Bosomworth et al. (2018), Bosomworth (2022), and Cowie et al. (2013). A two-way ANOVA was used to examine the effects of ground cover, clay, and silt content on POC and DOC. For POC data, analysis was performed on log-transformed to meet normality assumptions.

Results

Particulate Organic Carbon in Runoff

Ground cover had a significant influence on POC loads ($P < 0.001$) where increased ground cover was associated with decreased POC loss. A similar effect was associated with the presence of clay ($P < 0.03$) (Figure 1). Silt had no statistical effect ($P = 0.2$). Soil type also had a significant effect ($P < 0.001$), particularly where there was a high percentage of fine fractions in the parent soil. Where ground cover was $< 10\%$, Sodosols exhibited the highest mean POC load (28.9 kg/ha) followed by Vertosols (23.5 kg/ha) and Dermosols (6.0 kg/ha). As ground cover exceeded 10% total cover, POC loads decreased significantly by up to 88%, depending on soil type. POC was 2 to 99% of the total organic carbon fraction depending on soil type, ranging from 2 to 82% for Dermosol, 62 to 99% for Sodosols, and 2 to 99% for Vertosols. Soil organic matter in the parent material was not significant for POC load.

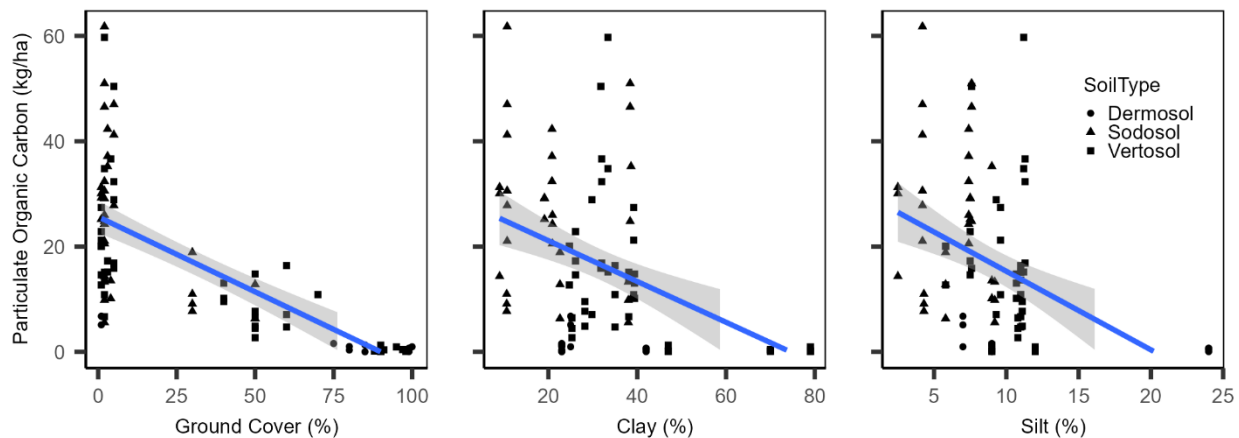


Figure 1: Particulate organic carbon (POC) loads in runoff (kg/ha) and the relationship to ground cover (left) and fractions of clay (centre) and silt (right) in the parent soil. Data points represent raw observed values, with the trendline based on log-transformed data to meet normality assumptions for statistical analysis.

Dissolved Organic Carbon in Runoff

Ground cover had no significant effect on loss of DOC in runoff ($P>0.8$) (Figure 2). Clay content was marginally significant ($P=0.06$), and silt content had no effect ($P>0.2$). Soil type was the main driver for DOC loads ($P=0.002$). An effect between ground cover and soil type was significant for DOC loads ($P<0.001$). Results suggest as clay fractions in the soil increase, the DOC loads tend to increase. However, once clay exceeds 50%, an inverse relationship was found. Where soils had $<50\%$ clay, clay content had a significant effect on DOC load ($P<0.001$). DOC was 1 to 98% of the total organic carbon load, ranging from 18 to 98% for Dermosol, 1 to 38% for Sodosols, and 1 to 98% for Vertosols. Soil organic matter in the parent material was not significant for DOC load.

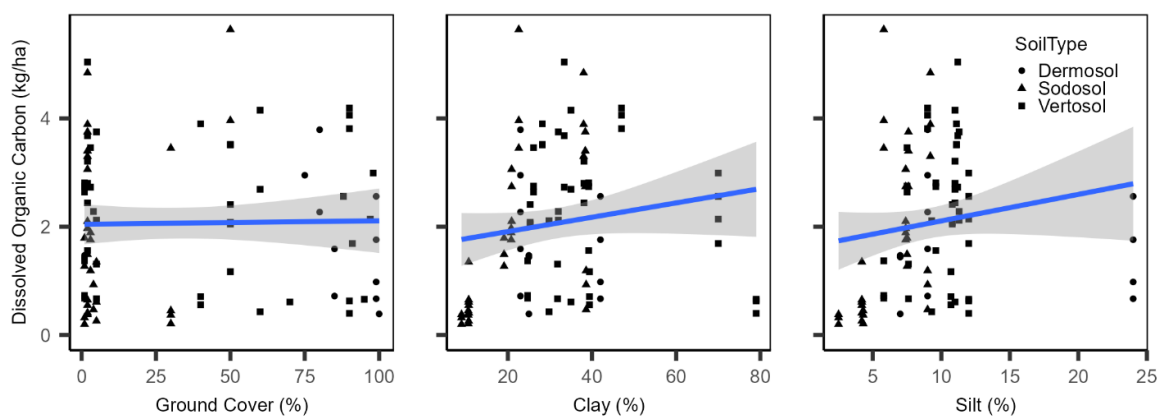


Figure 2: Dissolved organic carbon (DOC) loads in runoff (kg/ha) and the relationship to ground cover (left) and the fractions of clay (centre) and silt (right) in the parent soil.

Discussion

POC mobilisation in runoff was driven by erosion processes including raindrop impact and subsequent sediment entrainment. Where there was minimal vegetative protection, these processes facilitated the detachment and transport of fine soil particles, thereby increasing sediment and associated POC loads.

Managing ground cover will influence the contribution of this labile fraction of organic carbon. Many studies have shown variation in ground cover because of agricultural impacts such as grazing is strongly related to sediment export (Bosomworth et al. 2018; Thornton and Elledge 2021), and our results reinforce the importance of cover.

DOC mobility is primarily driven by soil type and the detachment and transport of finer particles associated with the parent soil. DOC loads are also influenced by the interaction between bare ground and clay fractions present in the *in situ* soil. Managing the DOC contribution isn't as easily achieved as it is for POC because of the variable nature of soil texture; however, increasing ground cover reduces fine particle detachment from raindrop impact and will impede both POC and DOC export.

The soils used in this study were located within the Fitzroy and Burdekin Basins, which, combined, represent 70% of the GBR catchment, from which 1300kt of fine sediment is exported annually (Prosser and Wilkinson 2024). Fine sediments, <20 µm, are easily suspended and transported, which includes the DOC fraction. Studies by Bainbridge et al. (2012) show that particles <16 µm are capable of sustained suspension and discharge from the end-of-catchment well into the Reef lagoon.

Packett (2017) showed that rainwater also serves as an additional source of DOC which could have impacts on the GBR, but also the terrestrial carbon pool. While concentration of DOC in rainfall from that study (range 0.7 to 2.3 mg/L) is lower compared to the mean soil-derived DOC reported here (8.1 mg/L; range 0.9 to 22.4 mg/L), its contribution to the total carbon budget should not be discounted. Given the nature of eroded organic fractions, which are prone to rapid mineralisation, quantifying their contribution in runoff from GBR catchments would provide further important insight into the carbon budget.

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