Using Nutrient Balance to Estimate Net C Balance in Landslide-Prone Pastoral Hill Country: Testing the "Dynamic Equilibrium" Hypothesis in New Zealand Soft-Rock Landscapes

W. Troy Baisden, Roger L. Parfitt and ***Noel A. Trustrum***

Landcare Research, Private Bag 11052, Palmerston North, New Zealand
E-mail: BaisdenT@Landcare.cri.nz

Abstract: Given recent negotiations of the Committee of Parties to the United Nations Framework Convention on Climate Change, soil C accumulation related to soil conservation efforts may be counted as C credits in national C balance calculations under the Kyoto Protocol. It has been proposed that in some instances, erosion can establish a dynamic equilibrium that results in a C sink corresponding to ongoing recovery of C in eroded soils combined with ongoing C accumulation in terrestrial sediments. Given this hypothesis, full accounting for erosion and soil conservation in the C budgets of dynamic landscapes may represent a significant challenge due to indirect effects of burial and nutrient dynamics on the balance of plant production and decomposition of soil organic matter (SOM). As a method for evaluating the 'dynamic equilibrium' hypothesis, we examine the burial and availability of eroded C and nutrients using a combination of field data and models. Landslides represent a model system for studying erosional effects on C and N dynamics because they offer the ability to study easily identifiable events representing a known proportion of the landscape. We therefore investigate the C and N balance of pastoral land on soft-rock landscapes in New Zealand that commonly undergo shallow landslides. Soil cores driven to the bedrock interface indicate that 23- and 37-year-old landslides have recovered to –50% and 72% soil C stock, respectively, when compared with cores from uneroded sites on similar slopes and aspects. Locally, this upland soil loss represents the removal of 36 Mg/ha—90 Mg/ha. However, a portion of the eroded C may be retained on land if landslide debris is not fully evacuated by streams, and the eroded C can also become buried in marine environments. To determine whether the net effect of erosion can represent a sink for atmospheric CO_2, we will combine the rate of upland soil C recovery with representations of the proportion of eroded C sequestered in sediments.
Keywords: carbon, nitrogen, erosion, kyoto, dynamic equilibrium

1 Introduction

Stallard (1998) estimates that human-induced erosion may result in the burial of 0.6—1.5 Pg C in terrestrial sediments alone. Terrestrial burial of eroded C is generally not considered in representations of the global C cycle, yet Stallard's estimate is in the order of the uncertainty and imbalance in estimates of the global C cycle. Efforts to evaluate the C sink effect of Stallard's "dynamic equilibrium" hypothesis have focused on hillslopes where rates of erosion remain one of the main sources of uncertainty in calculations of C budgets (Harden *et al*., 1999; Manies *et al*., 2001; Rosenbloom *et al*., 2001). To reduce uncertainties in erosion rates, we examine C budgets in landslides where erosion can be calculated for the landslide event based on scar dimensions. We establish a framework for examining the net effect of erosion on atmospheric CO_2 in pastoral soft-rock landslide terrain by combining rates of soil C recovery on the scar with scenarios describing the fate of eroded C.

2 Methods

The recovery of soil C following landslide events was examined by sampling landslide scars of known age for soil C and N in steep sheep/cattle pasture in the erodible Wairarapa region of New Zealand (Trustrum *et al*., 1984). Scars of varying ages were sampled to 20 cm depth in 1984 (Lambert *et al*., 1984), and resampled in 2001. In 2001, 7-cm-diameter cores were also collected to the depth of the bedrock interface and analysed for C and N. In all cases, soils were also collected and analysed from adjacent areas on similar slopes and aspects that had not undergone landsliding since forest clearing –100 years ago.

The recovery of soil C and N was simulated using the CENTURY 4.0 model (Parton *et al.*, 1987). Rates of N-fixation were set using data on N-fixer abundance (Lambert *et al.*, 1984) and established rates of N-fixation for each species. CENTURY simulations for both slipped and unslipped soil included sheet erosion of 0.4 Mg/ha, as estimated from a similar landscape where eroded C was trapped and recorded in lake sediments (Trustrum *et al.*, 1999).

3 Results and discussion

Soil cores driven to the bedrock interface indicate that 23- and 37-year-old landslides recover ~50% and 72% soil C stock, respectively, when compared with cores from uneroded sites on similar slopes and aspects (Figure 1). Locally, this upland soil loss represents the removal of 36 Mg/ha—90 Mg/ha. Although it is possible that differences between sites existed, it is most likely that the 37-year-old scar contains more C than the 23-year-old scar as a result of revegetation and recovery. Much of the lost soil organic matter (SOM) is from deep in the soil profile and probably resistant to decomposition. The deep, resistant portion of the SOM will take much longer to recover than the SOM in the upper 20 cm of the soil profile (discussed below). Resistant SOM may be less likely to be oxidized to CO_2 during transport or in depositional environments, however, so it could have relatively little net source or sink activity.

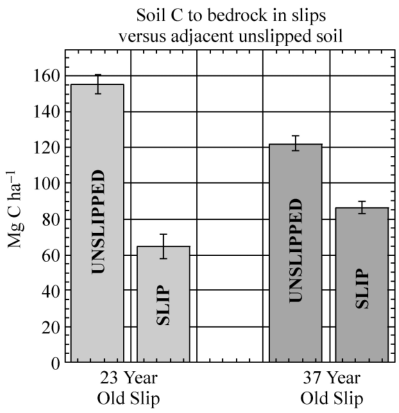

Fig. 1 Soil organic C in replicate soil cores taken to the bedrock interface in landslide scars and adjacent unslipped soil.

Soil C data for shallower (20 cm) soil depths were available from pasture productivity studies undertaken in 1984 (Figure 2). The same sites were resampled in 2001 and are also plotted on Figure 2. The agreement of 1984 and 2001 data demonstrate that the chronosequence constructed using scars of different ages correctly describes soil C recovery at a given site. Comparing the scars to unslipped soil, soil C appears to recover to approximately 80% of unslipped values over 50 years. This 50-year recovery represents approximately 70 Mg/ha, and does not appear to be strongly dependent on aspect.

Use of the CENTURY ecosystem model to simulate the recovery of SOM on landslide scars demonstrates the importance of P and N as nutrient limiting C accumulation in SOM. Using standard New Zealand pasture vegetation in CENTURY, the model describes a balance between input and output budgets of N from the "ecosystem". The input budget is represented by N-fixation, which can best be represented by combining the dry mass of N-fixing plant species (Lambert *et al.*, 1984) with estimated rates of N-fixation for each species. The output budget is represented by estimates of SOM loss due to sheet erosion in a similar landscape(Trustrum *et al.*, 1999). In this case, N budgets can assist greatly in constraining C budgets because C accumulation is mechanistically linked to P availability and N inputs via symbiotic fixation.

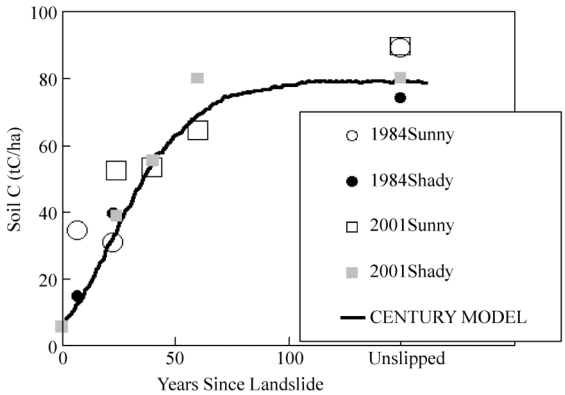

Fig. 2 Soil C in the upper 20 cm of the soil profile measured in landslide scars and in unslipped areas. The solid line shows a simulation of recovery on a fresh scar using the CENTURY model.

With adequate estimates of soil C recovering on landslide scars, it is possible to establish a framework for evaluating the net effect of landsliding to atmospheric CO_2. Given that the landslide scars studied recover approximately 70 Mg/ha over 50 years, we have established one important component of the net C budget. To complete the framework, we must represent the fate of the ~90 Mg/ha that moved during the landslide event. If this eroded C is oxidized completely to CO_2, then a net source of 20 Mg/ha still exists over 50 years. If a large percentage of the eroded C is sequestered in terrestrial or marine sediments, then a net C gain exists from the atmospheric perspective. This concept can be represented as:

$$N = R - O_C L_C \qquad (1)$$

where N represents the net effect of the landslide on atmospheric CO_2 after 50 years or longer, R is soil C reaccumulated after 50 years, L_C is the soil C moved downslope during the landslide event, and O_C is the proportion of L_C subsequently oxidized to CO_2. While relatively simple, equation (1) represents a net effect of an erosion event in an appropriate manner for landscapes similar to New Zealand's steep soft-rock pastures. We realise that although this study is focussed on landsliding, other erosion processes like water erosion must be considered to test the "dynamic equilibrium" hypothesis fully over large catchment and regional scales.

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