Understanding the erosion of semi-arid landscapes subject to vegetation change: a combined approach using monitoring, isotope and ^{14}c analysis.

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ABSTRACT
The degradation of grasslands is a common problem across semi-arid areas worldwide. Over the last 150 years much of the South-Western USA has experienced significant land degradation, with desert grasslands becoming dominated by shrubs and concurrent changes in runoff and erosion which are thought to propagate further the process of degradation. Field-based experiments were carried out to determine how runoff and erosion vary at stages over a transition from a black grama (*Bouteloua eriopoda*) grassland to creosotebush (*Larrea tridentata*) shrubland at the Sevilleta NWR LTER site in New Mexico. $\delta^{13}C$ and $\delta^{15}N$ analyses were carried out to investigate the age and potential provenance of eroded sediment.

Keywords: Erosion, semi-arid, monitoring, isotope, soil organic matter, vegetation change

INTRODUCTION
At the Sevilleta National Wildlife Refuge, existing knowledge of grassland and shrubland vegetation dynamics is confined to a few photographs and anecdotal accounts. Hence, there is a dearth of quantitative data to describe the grassland to shrubland transition. The grasslands are composed primarily of C4 species and the shrublands C3 species. During photosynthesis C4 plants discriminate less against the heavier ^{13}C isotope than C3 plants (Lobe et al. 2005), therefore, C4 grasses, such as black grama, are enriched in ^{13}C relative to C3 shrubs such as creosotebush, thus, plants with C3 and C4 photosynthetic pathways have unique $\delta^{13}C$ values which are not altered significantly during decomposition, and so the $\delta^{13}C$ of soil organic carbon reflects the relative contribution of plant species with C3 and C4 photosynthetic pathways to community net primary productivity (Boutton et al. 1998). Consequently, $\delta^{13}C$ analysis of soil organic matter (SOM) through the soil profile presents a direct and powerful technique to reconstruct vegetation change over semi-arid grassland and shrubland areas (Boutton et al. 1998). The isotopic signals of C3 and C4 plants are:

C3 32 to – 22 % ; -27% average
C4 -17 to – 9 % ; -14% average (Krull et al. 2005)

In a steady-state soil system the $\delta^{13}C$ value of the input C (litter and roots) is similar to the $\delta^{13}C$ value of surface SOM (Boutton et al. 1998), whereby any large scale deviation from this would be an indication of a changing ecosystem (Krull et al. 2005). The $\delta^{13}C$ signal from contributing vegetation will be greatest immediately following vegetation change, but will decrease over time as carbon from the previous plant community decays out of the organic carbon pool and is replaced by new carbon derived from the current plant community, determined by the organic matter turnover rate (Boutton et al. 1998).

However, it is known that soils in degraded environments are not in steady state, due to the often high rates of erosion that have occurred previously, and the ongoing degradation of the landscape. Thus, understanding the $\delta^{13}C$ and $\delta^{15}N$ signal in such environments represents a significant and interesting challenge. In addition, in environments where vegetation change has occurred, the high levels of redistribution of sediments and organics around the landscape affords an opportunity to evaluate whether eroded sediments are sourced from areas dominated by C4 grass species or C3 shrub species. Such information will determine whether the sediment that is eroded is old – i.e. provenanced from previously un-eroded surfaces under grass, or younger and eroded from areas dominated by the newly established shrub species

OBJECTIVES

1) To use $\delta^{13}C$ and $\delta^{15}N$ data from soil organic matter to infer the time course of changes in vegetation.
2) To use $\delta^{13}C$ and $\delta^{15}N$ values of soil organic matter to document shifts in the relative productivities of C4 and C3 functional types over a grassland to shrubland ecotone at the Sevilleta National Wildlife Refuge.
3) To use ^{14}C analysis of sediment that has been transported during flow events to determine, at different stages over the grassland to shrubland transition, the relative contributions of eroded sediment from soils under the influence of shrub species (labelled with the C4 isotopic signature) and sediment eroded from non shrub areas (labelled with the C3 isotopic signal).

METHODS

Four monitoring sites have been established over a grassland to shrubland ecotone that are assumed to be representative of different stages of the grassland to shrubland transition (Turnbull et al. in press) At each site, three soil cores were taken, down to the depth of the caliche layer. Bulk soil samples were collected for the top 2cm and then at 5cm depth increments thereafter. Bulk soil samples were sieved through a 2mm screen and the fraction less than 2mm was ground using a pestle and mortar until the sample became a homogeneous fine powder. To remove inorganic carbon from the soil, 75ml of 1N HCl was added to approximately 5g of ground soil and left for 16 hours and then filtered through a glass fibre filter paper and washed with 100ml deionised water three times to remove HCl. Samples were then air dried and stored in capped polyethylene tubes prior to analysis. Pre-treated samples from the three cores from each of the four sites were then analysed for $\delta^{13}C$ and $\delta^{15}N$. In addition, samples of both eroded sediments and existing vegetation (both C3 and C4) were taken from each plot to establish the relative $\delta^{13}C$ and $\delta^{15}N$ values across all of the sites. These samples were analysed adopting the same protocols as outlined above.

STUDY SITE

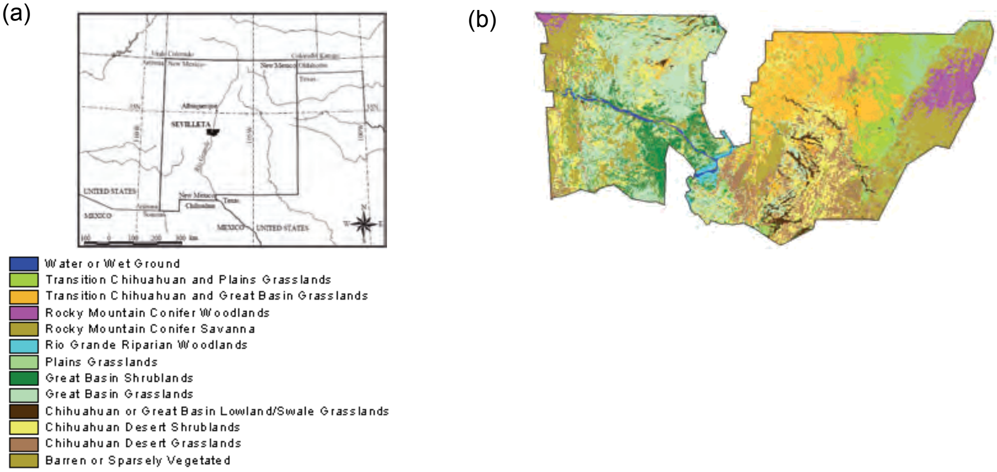

Figure 1. (a) Location of the Sevilleta National wildlife Refuge in New Mexico, (b) Vegetation map with nominal 0.5ha resolution derived from unsupervised classification of 12 Landsat thematic images (NDVI transformed).

RESULTS AND DISCUSSION

At each site, there is variation in the δ^{13}C signal of the organic matter at the sampled depth intervals between the three cores (Figure 2). Therefore, it is evident that the δ^{13}C signal of the organic matter at a given depth from the soil surface is spatially variable. Results from Plots 1, 2 and 4 show a general increase in the percentage of C_4 derived organic matter with depth. Increases in the δ^{13}C with depth have been observed in previous studies and have been primarily attributed to microbial fractionation and the contribution of microbial biomass (Krull *et al.* 2005). The trend of increasing δ^{13}C values over Plot 1 are comparable to the trends observed over grasslands in other studies (e.g. Boutton *et al.* 1998; Krull *et al.* 2005), although the δ^{13}C values of core A and C in the surface horizons are particularly low for grasslands. The δ^{13}C values of Plots 2 and 3 (the intermediate plots) suggest that a greater percentage of organic matter over these plots has been derived from C_4 plants than the grass-end-member. δ^{13}C values at Plot 2 increase gradually with depth. At Plot 3 however, δ^{13}C values remain relatively constant through the soil profile. Results from Plot 4 show a greater contribution of organic matter derived from C_3 plants compared to all the other plots. The δ^{13}C values increase greatly between the soil surface and 5cm depth to a mean value of -19%. δ^{13}C continue to increase with depth, but values are lower than δ^{13}C values at comparable depths at Plot 1. Here, the percentages of C_4 derived organic matter are high, from the surface down through the soil profile. Even the surface δ^{13}C signals on Plot 3 are greater than the surface δ^{13}C signals on Plot 1, the grass end-member.

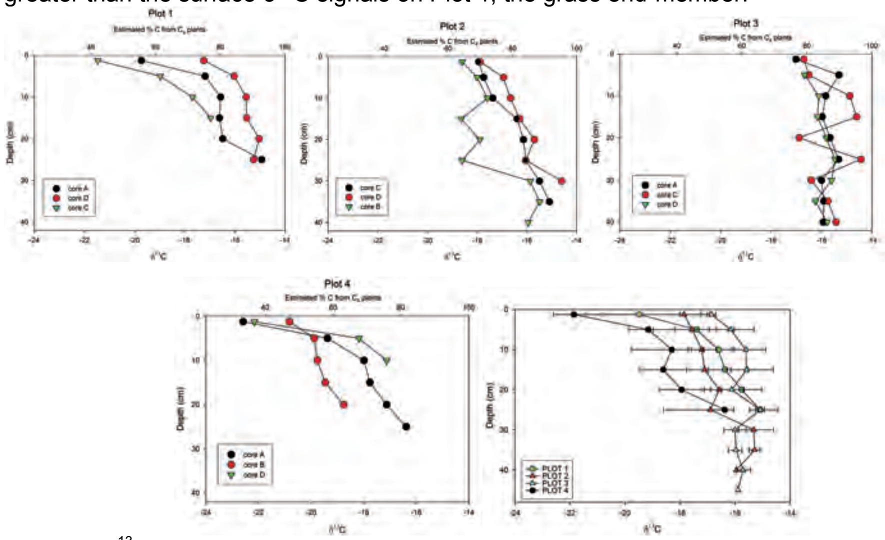

Figure 2. δ^{13}C (%) values of soil organic carbon from the sites located over the grass-shrub ecotone. (The bottom plot shows results from all sites together – symbols represent the mean δ^{13}C at each depth at each site, and the error bars show maximum and minimum values).

In order to interpret these data (and data describing δ^{15}N cores) more fully, it is clear that some ability to relate each profile to a precise baseline is needed. It is probable that the variation between sample points at specified depths, is controlled by the extent to which soil erosion has occurred at each sampling point revealing older, deeper soil horizons. Therefore, the profile of the core taken at each sampling location will depend upon the extent to which erosion has taken place both locally and across the whole plot at each stage of the transition across the grass – shrub ecotone. Indeed, on the intermediate plots which display high δ^{13}C values, even at the surface, it is likely that so much soil erosion has occurred here, that older soil horizons are now exposed which have higher δ^{13}C values. This suggestion is supported (for example) by the δ^{13}C signal of organic matter on Plot 1 below 10cm being similar to the δ^{13}C signal of organic matter throughout the profile on Plot 3.

To understand the dynamics of sediment movement within each plot and between plots in the ecotone, it is illustrative to look at the data describing δ^{15}N and δ^{13}C for C_4 and C_3 vegetation, soils from each plot and sediment eroded from each plot (Figure 3). The end members of shrub and grass exhibit clear differences, but what is also immediately obvious is that the signal from the soils and eroded sediments is different. It seems likely that the plot 4 sediments are sourced from more degraded, older soils, which would be dominant in the shrub covered part of the ecotone. Conversely, it seems likely that the plot 1 sediments are sourced from the younger surface soils, prevalent under the pristine grasslands. However, the mixed story that is shown for the intermediate plots is less easy to understand, though by implication it might be assumed that such a signal represents the erosion of sediments from soils rich in both C_3 and C_4 vegetation.

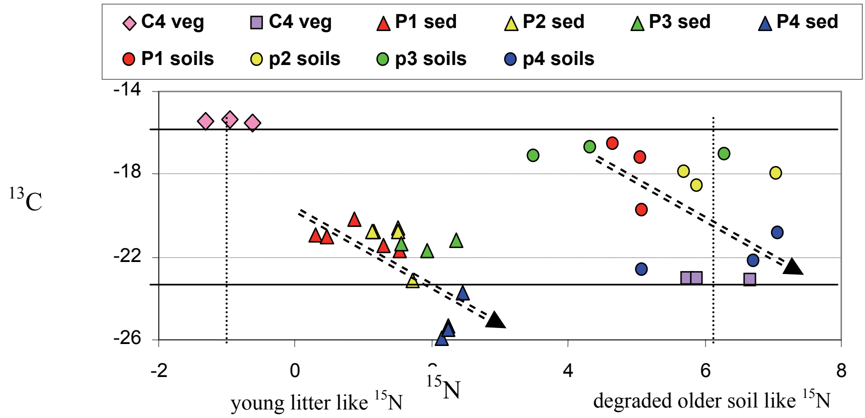

Figure 3. δ^{15}N vs δ^{13}C values for vegetation end members, in situ soils and eroded sediments across the ecotone.

CONCLUSIONS

The preliminary results presented here demonstrate that using carbon and nitrogen isotope signals to understand vegetation change in semi-arid environments has the potential to elucidate not only timing but also rates of change. These data must be combined with absolute dating techniques, such as ^{14}C dating, to ensure that isotope signatures at each depth in soil profiles beneath the vegetation transition are comparable in terms of the age of each soil profile.

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