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Changes in soil microbial biomass, metabolic quotient, and organic matter turnover under Hieracium (H. pilosella L.)

Abstract In New Zealand Hieracium is an opportunistic plant that invades high country sites more or less depleted of indigenous vegetation. To understand the invasive nature of this weed we assessed the changes in soil C, N and P, soil microbial biomass C, N and P contents, microbial C:N and C:P ratios, the metabolic quotient, and turnover of organic matter in soils beneath Hieracium and its adjacent herbfield resulting from the depletion of tussock vegetation. The amounts of soil organic C and total N were higher under Hieracium by 25 and 11%, respectively, compared to soil under herbfield. This change reflects an improvement in both the quantity and quality of organic matter input to mineral soil under Hieracium, with higher percentage organic C and a lower C:N ratio. The microbial biomass C, N and P contents were also higher under Hieracium. The amount of C respired during the 34-week incubation indicated differences in the nature of soil organic matter under Hieracium, with the unvegetated “halo” zone surrounding Hieracium patches, and herbfield (depleted tussock grassland). Decomposition of organic matter in these zones showed that Hieracium soil had the greatest rate of CO₂ respired, and the halo soil had the lowest. We relate the enhanced organic C turnover to the invasive nature of Hieracium. Net N mineralization was significantly lower from Hieracium soil (57 mg N g⁻¹ soil N) than from herbfield and halo soils (74 and 71 mg N g⁻¹ soil N, respectively), confirming that the nature of organic N in Hieracium soil is different from adjoining halo and herbfield soils. It seems plausible that specific compounds such as polyphenols and lignins released by Hieracium are not only responsible for increased organic N, but also control the form and amount of N released during organic matter transformations. We conclude that the key to the success of Hieracium in the N-deficient South Island high country of New Zealand lies in its ability to control and sequester N supply through modifying the soil organic matter cycle.

Key words Tussock grassland · High country · Microbial biomass · Organic C and N turnover · Hieracium invasion

Introduction

The invasion and continuing dominance of Hieracium (H. pilosella L.), a mat-forming, stoloniferous flatweed with an extensive underground root mass, in high country tussock grasslands of New Zealand is a serious problem, and a major threat to the ecological and economic sustainability of South Island high country pastoralism. Makepeace et al. (1985) observed that fescue tussock (Festuca novae-zelandiae) growing in areas of dense Hieracium contained low N and P. Treskonova (1991) related Hieracium invasion to “degradation” of tussock grasslands, but with little reference to soil properties. There is no doubt, however, that low tussock cover (Chionochloa, Festuca and Poa sp.) is broadly correlated with Hieracium dominance (Hunter et al. 1992). Recent research has shown that soils beneath Hieracium patches are more acid and contain more organic C and nutrients than soils under surrounding vegetation (McIntosh and Allen 1993; McIntosh et al. 1995; Boswell and Espie 1998). It appears that Hieracium is able to modify soils to its own advantage, and McIntosh et al. (1995) suggested the ability of Hiera-
to take up N from soils which it was invading was the reason for its success. The consequences of the observed soil changes can be predicted only if the dynamics of and functional mechanisms in soils under *Hieracium* and adjacent herbfield (depleted tussock grassland) are better understood.

In previous studies neither soil microbial biomass nor organic matter dynamics was studied. There is considerable evidence that microbial biomass C, N and P measurements could be used to evaluate the influence of land-use change on soils (Yeates et al. 1997; Yeates and Saggar 1998) and how organic matter turnover controls the fluxes of nutrients. Microbial biomass measurements combined with soil respiration (metabolic quotient, $q_{CO_2}$) have frequently been used as an index of soil development or degradation (Insam et al. 1989) and to assess the quality of organic matter input (Anderson and Domsch 1990, 1993).

Because *Hieracium* invasion occurs in tussock grasslands more or less depleted of their original cover of tussock species (*Chionochloa, Festuca* and *Poa* sp.), and its growth causes profound changes in the chemical soil properties, it is relevant to study its effects on changes in microbial biomass and organic C turnover. Information on changes in microbial biomass, $q_{CO_2}$ and organic C turnover may help understanding of the processes that aid the invasion of this and other weeds, and discourage grass species growth and persistence.

Our aim in the present study was to determine the pattern of change in microbial biomass C, N and P and metabolic quotient in the different soil zones (Fig. 1) caused by *Hieracium* invasion of depleted tussock grasslands. A second aim was to examine the decomposition of organic matter in these zones to determine the impact of invasion on organic matter turnover. This information could also be utilized to determine whether progressive * Hieracium* invasion was correlated with the “quality” of organic matter inputs.

### Materials and methods

**Soil sampling and analysis**

The site used by McIntosh and Allen (1993) and McIntosh et al. (1995) for this study was on Glencairn Station (NZMS 260 H39 827490), near Twizel, South Island, New Zealand. The site is at 440 m altitude, receives 500–600 mm precipitation, has a northerly aspect and a 15° slope. Soils at the site are developed on thin loess of greywacke origin over bouldery fan alluvium derived from greywacke of the Benmore Range. The soils are classified in the NZ Soil Classification (Hewitt 1992) as Immature Pallic Soils and in Soil Taxonomy (USDA 1994) as Typic Ustochrepts. The soils are S-deficient but natural levels of available P are moderate (Olsen-P=11; site G4, McIntosh et al. 1985). The sites have never been fertilized.

Since 1978 the site has been grazed at an estimated stocking rate of 0.6 SU ha$^{-1}$ (SU = Stock Unit; one stock unit consumes approximately 550 kg DM (Dry matter) ha$^{-1}$ and is equivalent to 35 kg liveweight lamb or 50–60 kg liveweight ewe). No *Hieracium* was noted in 1978 but since that time *Hieracium* has established in numerous patches. At the time of sampling *Hieracium* patches typically had 0.5–1.2 m diameter and almost 100% *Hieracium* cover with no other plant species present. Patches were surrounded by an approximately 15-cm wide “halo” of almost bare ground (Fig. 1). Some patches larger than about 1.5 m diameter had senescence centres. According to McIntosh et al. (1995) the diameter of the patches is expanding at approximately 13 cm per year; this allows progressive changes associated with *Hieracium* invasion into depleted tussock grassland to be studied.

At the sampling site four locations (replicates) were chosen for sampling, each having a circular *Hieracium* patch, a regular halo, and *Hieracium*-free herbfield, as described by McIntosh et al. (1995) and illustrated in Fig. 1. In 1993 the herbfield was dominated by *Leonotodon taraxacoides* (13%) with *Hieracium pilosella*, *Rosa rubiginosa*, *Trifolium arvense*, *Anthoxanthum odoratum*, *Muehlenbeckia complexa*, *Melicytus alpinus*, *Carex breviculmis*, *Bromus spp.* and *Wahlenbergia gracilis* (all <5%; McIntosh et al. 1995). Soil was sampled to a depth of 10 cm, which in pastoral soils has usually been considered as the upper layer for soil microbial biomass and nutrient estimations (Brookes et al. 1985). Using a spade, a topsoil sample of approximately 1 l was taken from each patch centre, halo, and adjacent herbfield (within 0.5 m of the halo), giving four replicates for each “treatment”. The samples were stored at 4°C in plastic bags, hand-sorted to remove vegetation and litter, and sieved moist through a 5-mm sieve. Subsamples of the sieved soil were stored moist at 4°C for soil microbial biomass C, N and P analysis and the incubation study.

Air-dried samples were used for the total C, N and P analyses. Total C in soils was analysed by a combustion method (Vance et al. 1987). Fumigated and non-fumigated soils were extracted with 0.5 M K$_2$SO$_4$ for 30 min (1:5 soil:extraction ratio), filtered, and then an aliquot was analysed for C using a TOC 5000 analyser. The oxidizable C obtained from the fumigated samples minus that from the non-fumigated samples was taken to represent the microbial-C flush and converted to microbial-biomass C using the relationship:

$$\text{Microbial C} = \text{C flush} / 0.41 \quad (\text{Wu et al. 1990})$$

**Soil microbial biomass C**

Soil microbial biomass C was determined by a fumigation-extraction method (Vance et al. 1987). Fumigated and non-fumigated soils were extracted with 0.5 M K$_2$SO$_4$ for 30 min (1:5 soil:extraction ratio), filtered, and then an aliquot was analysed for C using a TOC 5000 analyser. The oxidizable C obtained from the fumigated samples minus that from the non-fumigated samples was taken to represent the microbial-C flush and converted to microbial-biomass C using the relationship: