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SOIL CHANGES UNDER MOUSE-EAR HAWKWEED (*HIERACIUM PILOSELLA*)

Summary: The rate of spread of mouse-ear hawkweed (*Hieracium pilosella*) patches, the effect of hawkweed on soil properties, and the nutrient content of hawkweed biomass was investigated on grazed unfertilised land on Glencairn Station (altitude 440 m, mean annual rainfall 500–600 mm) in the Mackenzie basin, southern South Island, New Zealand. Pallic soils (Typic Ustochrepts) under hawkweed patches and under surrounding herbfield were analysed for exchangeable cations, organic C and total N. Total nutrients in hawkweed and herbfield biomass were measured. Previous results showing lower topsoil pH and more organic C under hawkweed than under herbfield were confirmed. Soils under hawkweed had higher values of exchangeable Ca and Mg than soils under herbfield. The hawkweed patches had 85% more biomass (herbage plus roots) per unit area than the surrounding herbfield, and hawkweed biomass contained about three times the Ca and K of the herbfield biomass. In each of two successive years hawkweed patches, which had initial diameters of 1–1.2 m, increased their diameter *c.* 13 cm by expanding into the "halo" of bare soil surrounding them. Mean patch area increase was 25% per year. The halo soil contains less organic C and total N and has lower total exchangeable cations values compared to soils under hawkweed and herbfield. The halo, which is underlain by hawkweed roots, appears to be a zone in which nutrients are depleted to the benefit of the hawkweed patches. As patches grow in size, the advantage that the inferred nutrient depletion in the halo confers on hawkweed patches will become limited to patch margins.

Keywords: *Hieracium pilosella*; hawkweed; plant-soil relationships; soil carbon; soil pH; soil nitrogen; soil nutrients; interference; halo effects.

Introduction

Previous work

Several researchers have noted the relationship of *Hieracium pilosella* (hereafter named hawkweed) to soil properties. Scott (1975) reported that soils under hawkweed were more acid than soils under a number of commonly occurring plants in tussock grasslands. Makepeace, Dobson and Scott (1985) noted that fescue tussock (*Festuca novae-zelandiae*) had lower nitrogen (N) and phosphorus (P) content when growing in areas of dense hawkweed, and also noted effects of leaf washings of hawkweed on seed germination and root growth; some effects were attributed to phenolic acids in leaves. Treskonova (1991) related hawkweed invasion to "degradation" of tussock grasslands, but without reference to soil properties. Wiedera (1978) studied the influence of natural soil nutrient (total N, P, potassium (K), calcium (Ca) and magnesium (Mg)) variation on the competitive ability of hawkweed on drought-prone, "degraded" soils of Poland, and demonstrated that high K/Mg and Ca/Mg ratios favoured hawkweed growth. Davy and Bishop (1984) showed the importance of soil fertility in governing the success of hawkweed in competition with grasses: flower initiation in hawkweed was stimulated by addition of N, P and K but adding nutrients also stimulated competing grasses which led to declines of hawkweed populations either by shading (in rabbit exclosures) or by root competition (in grazed areas). McIntosh and Allen (1993) showed that soils beneath hawkweed patches in the Mackenzie basin were more acid, and contained more organic carbon (C), than soils under the surrounding vegetation; the observed zonation of vegetation around the patches indicated that hawkweed might be modifying the soil around it for its own advantage.

Aim

The study reported in this paper was conducted to find out more about (1) the rate of expansion of hawkweed patches, (2) the zonation of soil properties below and around hawkweed patches, and (3) the nutrient contents of soils and plants in hawkweed and non-hawkweed areas.

Site characteristics

The site used by McIntosh and Allen (1993), on Glencairn Station (NZMS 260 H39 827490) near

Twizel, South Island, New Zealand, was chosen. The site is at 440 m altitude, receives 500–600 mm rainfall, has a northerly aspect and 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 were previously mapped in the Meyer set (N.Z. Soil Bureau, 1968) but are now classified in the N.Z. Soil Classification (Hewitt, 1992) as Immature Pallic Soils and in Soil Taxonomy (U.S.D.A., 1994) as Typic Ustochrepts. The soils are S-deficient but natural levels of available P are moderate (Olsen-P = 11) (site G4, McIntosh, Sinclair and Enright, 1985). No fertiliser has been applied.

Since 1978 the site has been grazed at an estimated stocking rate of 0.6 ewe equivalents per hectare. It has significant but patchy hawkweed cover in herbfield areas derived from depleted grasslands. Typically hawkweed patches are 0.5–1.2 m diameter and have almost 100% hawkweed cover with no other species present. Patches are surrounded by an approximately 15 cm wide "halo" of almost bare ground (Fig. 1). Patches larger than about 1.5 m diameter may have senescent centres. No hawkweed was noted at the site in 1978 (P.D. McIntosh, *unpubl.*) Patch density is very variable: where patch density was estimated to be greatest there were 44 patches (*c.* 0.5–1.2 m diameter) per 100 m^2, with many smaller patches, and a few additional larger patches that appeared to be smaller patches that had joined.

On two transects within 100 m of the hawkweed site, on the same aspect, surveyed in 1993 (R.B. Allen, *pers. comm.*), there was 38% bare ground, 22% litter and 1% stones. Vegetation cover was 13% *Leontodon taraxacoides*, 4% *Hieracium pilosella*, 4% *Rosa rubiginosa*, 4% *Trifolium arvense*, 3% *Anthoxanthum odoratum*, 2% *Muehlenbeckia complexa*, 1% *Melicytus alpinus*, 1% *Carex breviculmis*, 1% *Bromus* spp. and 1% *Wahlenbergia gracilis*.

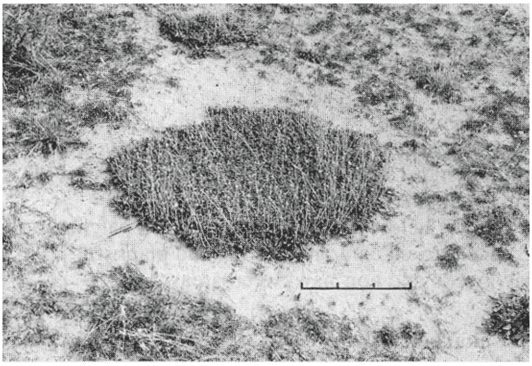

Figure 1: *Photograph of hawkweed (*Hieracium pilosella*) patch showing characteristic halo. Scale is 30 cm long.*

Methods

Plant nomenclature follows Allan (1961), Moore and Edgar (1970) and Webb, Sykes and Garnock-Jones (1988).

Ten hawkweed patches and surrounding herbfield, previously sampled by McIntosh and Allen (1993) were remeasured in March 1994 and March 1995 to ascertain the rate of hawkweed patch expansion in 1 and 2 years. In March 1994 soils from a further 10 patches, approximately 1.2 m diameter, without senescent centres, were sampled in a concentric pattern, starting from the centre of patches: *Centre* samples were taken from a zone *c.* 0–20 cm radius; *Intermediate* samples were taken from a zone at *c.* 20–40 cm radius; and *Margin* samples were taken from a zone at *c.* 40–60 cm radius. *Halo* samples were taken from bare soil areas with no hawkweed herbage and few other plants in the approximately 15 cm wide zone immediately surrounding hawkweed patches and *Outside* samples were taken from immediately surrounding herbfield in areas with no hawkweed. In each sampling zone 12 cores, 2.54 cm diameter and 7.5 cm deep, were bulked after removing vegetation from the tops of cores with a knife. In March 1995 these sampled patches were also remeasured.

Rainfall was measured at the Glencairn homestead, 4 km northeast of the study area, at the same altitude.

Soils were air-dried at 30°C and sieved through rotary 2 mm sieves using the standard soil preparation techniques of the soil laboratory at Invermay Agricultural Centre, Mosgiel, New Zealand. Using this method stolons and most fibrous roots form a tangled mass that does not pass through the sieve. No attempt was made to separate small fragments of dead and live roots that did pass through the sieve. Organic carbon was determined by Walkley-Black digestion, total nitrogen by Kjeldhal digestion, and pH in water (1: 2.5 soil: water ratio). Exchangeable cations were determined by unbuffered silver-thiourea extraction (Blakemore, Searle and Daly, 1987) at the same laboratory.

To compare the biomass and nutrient content of hawkweed vegetation and surrounding herbfield, 0.4 m^2 plots were sampled, two in randomly chosen hawkweed patches and two in adjacent herbfield. Live herbage (predominantly leaves and surface stolons) was removed from the soil surface with a knife. There was negligible litter and that present was included in the soil fraction. All the soil to 25 cm depth was removed for extraction of roots. Both herbage and roots were washed through a 2 mm sieve, the day after sampling, to remove adhering soil. Fine roots passing through the 2 mm sieve were separated by decanting initial washings through a 212 μm sieve and hand picking roots with tweezers. Finally roots were washed twice in distilled water. Herbage and root N was measured by a micro-Kjeldhal method used at Invermay and other total and trace elements were measured by X-ray fluoresence (XRF) spectroscopy by Southern Chemical Consultants, Invercargill, New Zealand. The total element concentration of topsoils at the site was also measured by XRF spectroscopy and, on the basis of the titanium content of soils and sampled herbage and roots, a correction for soil contamination of herbage and roots was made, on the assumption that titanium is not taken up by plants.

An estimate of pooled standard error of the difference between means (SED) was calculated for each soil property by analysis of variance using GENSTAT 5 (Lawes Agricultural Trust, 1993).

Results

The mean diameter of the 10 hawkweed patches sampled by McIntosh and Allen (1993) was 104 cm and in March 1994 it was 116 cm, i.e. in one year mean hawkweed patch diameter increased by 12 cm (SD=4.6). This was an area increase of 25% for the 1993-94 season, in which September–February rainfall was 518 mm. The 20 patches measured in March 1994 had expanded 14 cm (SD=7.1) by March 1995. This was an area increase of 24% for the 1994-95 season in which September–February rainfall was 262 mm. The halo was present at all times, i.e., the patch expanded over about half the halo in one year, but the halo moved outwards ahead of the patch, so that halo width was maintained.

Soils under hawkweed were more acid than soils under surrounding herbfield by up to 0.5 pH units, and contained more organic C (Fig. 2). Total N trends followed organic C trends. Soil exchangeable Ca, Mg and K values were invariably lowest in the halo and highest in the centres of hawkweed patches. Exchangeable Na values were uniformly very low (mean values were 0.06–0.07 milliequivalents 100 g^{-1}) (results not illustrated in Fig. 2). Total exchangeable cation values were higher in all zones of hawkweed patches than in outside vegetation, and values increased towards the centre of patches.

Total dry matter in the two hawkweed patches sampled was 85% higher than in surrounding herbfield. Except for S, nutrients expressed per unit area were all higher in the hawkweed patches than in the surrounding herbfield (Table 1), with P, Ca and K values in hawkweed biomass being about three times higher than levels in the herbfield.

Discussion

Because hawkweed patches are expanding, the spatial trends show how the patches progressively modify the soils of the surrounding herbfield.

The soil chemical results from the concentric sampling study confirm previous observations that soils under hawkweed are more acid than those under herbfield (McIntosh and Allen, 1993). As exchangeable cations increase in soils under hawkweed, the decline of soil pH cannot be attributed to net depletion of exchangeable cations. We suggest it is caused by organic matter accumulation resulting from greater dry matter production under the perennial hawkweed than under the mainly annual herbfield. Makepeace *et al.* (1985) noted that chlorogenic and caffeic acid were present in hawkweed roots but they were unable to detect these compounds in associated soils, so a direct influence of these compounds on soil pH seems unlikely. However, they also noted that phenolic compounds were leached from leaves into soils, and the possible effects of such compounds both on soil pH and on nutrient availability require further study.

Table 1: *Dry matter and nutrient contents (kg ha^{-1}; $\bar{x}$ ± standard deviation (n=2)) in biomass of hawkweed patches and surrounding herbfield.*

	Hawkweed patch		Surrounding herbfield		Total biomass	
					Hawkweed patch	Surrounding herbfield
	Herbage	Roots	Herbage	Roots	Herbage + roots	Herbage + roots
Dry matter	1679±88	2644±104	828±178	1507±330	4323	2335
N	28±2.1	23±8.0	17±3.1	16±0.6	51	33
P	6.5±0.6	4.7±0.1	2.0±0.4	2.7±0.5	11.2	4.7
S	1.7±0.1	1.7±0.3	1.1±0.4	1.6±0.2	3.4	2.6
Ca	21±0.7	21±1.4	8.4±2.1	8.5±<0.1	42	17
K	37±3.5	38±2.1	14.0±4.2	10±1.9	74	24
Mg	7.0±0.4	4.1±0.3	2.8±<0.1	2.3±0.1	10.9	5.1

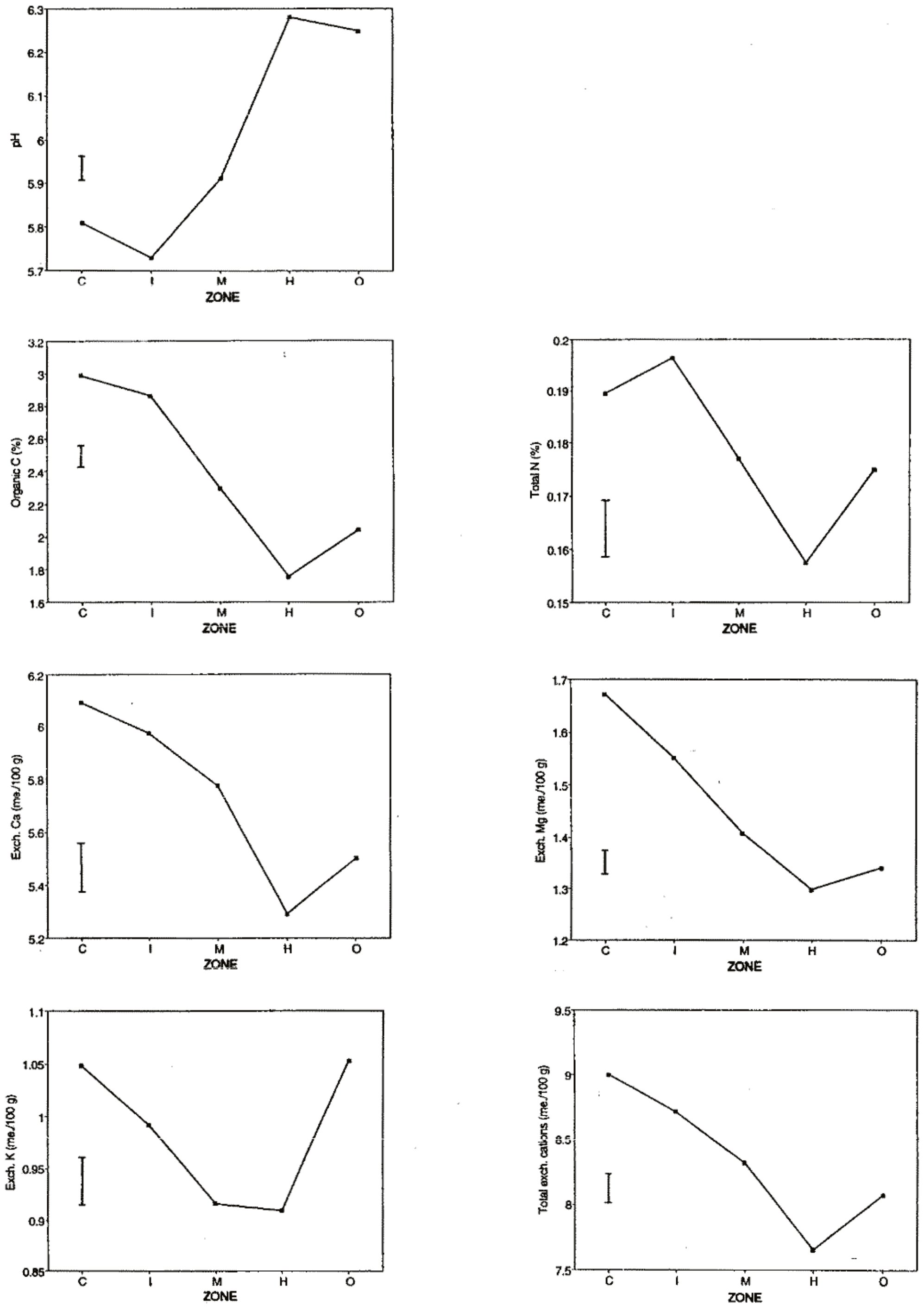

Figure 2: *Trends of pH, organic C, total N and exchangeable cations in soil zones of hawkweed patches and surrounding herbfield. C, I, M = centre, intermediate zone and margin of hawkweed patch respectively. H = halo. O = outside (herbfield). Vertical bar represents pooled SED.*

The pattern of higher nutrient content under hawkweed is similar to that described for *Lycopodium* fairy rings by Stone and Thorp (1971) except that no halo zone of nutrient depletion was noted by these authors. Although there is three times as much Ca and K in the hawkweed biomass as in the biomass of the surrounding herbfield, the 0–7.5 cm deep soil under hawkweed is not depleted in these cations. While we recognise that seasonal changes of both biomass and nutrient content of biomass can occur, the present data provide no indication that the lower total exchangeable cation content of herbfield ("outside") soils is a result of uptake into present herbfield biomass. Some of the Ca and K in hawkweed biomass may have been obtained from deeper layers not sampled, but the low values of nutrients in halo soils and the observation that halo soils are underlain by roots of hawkweed suggest that halos may be supplying at least some of the nutrients for hawkweed patches. However, it is possible that lower levels of nutrients in halo soils could be incidental to other processes occurring, e.g., intense competition for soil moisture. That patch expansion occurred at a similar rate in the "wet" 1993-94 season and the "normal" 1994-95 season is circumstantial evidence that competition for water is not the dominant process.

We suggest that the halo is a zone of N and cation depletion, and that uptake of nutrients from halos confers a benefit on hawkweed patches, and possibly gives patches an advantage over herbfield vegetation into which the hawkweed patches are expanding. However, the process cannot confer a competitive advantage to patches indefinitely, as patches will reach a size at which (a) nutrients cannot be translocated from the halo to the centre of a hawkweed patch via roots and stolons; and (b) the nutrients mobilised in the halo are only a small proportion of total patch requirements. Consequently, in grazed, unfertilised hill country, where there are continuous overall nutrient losses (O'Connor and Harris, 1991), plants at the centre of a hawkweed patch are eventually likely to become nutrient deficient. On these soils with moderate to high values of exchangeable cations and moderate P status, but very low organic C and total N values, N is likely to be the first nutrient to become limiting.

Conclusion

The results show that at this site hawkweed patches expand by about 13 cm diameter in one year, which is equivalent to an area increase of 25%. Soils under hawkweed have higher values of organic C and exchangeable cations than soils under adjacent herbfield, and the previously reported acidifying effect of this species is confirmed. Changes in soils associated with hawkweed are progressive: the halo zone immediately outside hawkweed patches has lowest levels of organic C and exchangeable cations and the centre of patches has the highest levels.

Hawkweed patches have about 85% more biomass than grazed adjacent herbfield and about three times the weight of Ca and K contained in the herbfield biomass. The ability of hawkweed patches to rapidly colonise herbfields appears to be related to their ability to take up nutrients from the halo zone. The advantage that nutrient uptake from the halo provides for the nutrition of hawkweed patches is likely to become increasingly limited to patch margins as patches expand.

Acknowledgements

To B. and C. Aubrey, Glencairn Station, for permitting use of the site and for supplying rainfall figures; to Drs P. Johnstone and K. Dodds, Invermay Agricultural Centre, AgResearch, for assistance with statistical analyses; to Drs L. Basher, P. Clinton and O. Bosch for comments on drafts of the manuscript; to Drs P. Espie, G. Rogers and an anonymous referee for criticism of the submitted manuscript. To the Foundation for Research, Science and Technology for supporting the study under contract C09325.

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