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Rumicetum alpini Beger 1922 – species composition, soil-chemical properties, and mineral element content

In memory of Univ. Prof. Dipl. Ing. Dr. Erwin Lichtenegger

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Summary: The *Rumicetum alpini* Beger 1922 is a widespread plant community in mountainous regions in Austria. It represents a vegetation type poor in plant species, with only few grasses and legumes, but dominated by *Rumex alpinus*. The zoo-anthropogenic plant community is characterized by a relatively low nature conservation and agricultural value. The *Rumicetum alpini* represents a nitrogen-saturated ecosystem, rich in humus and nutrients, with a relative excess of potassium and periods of high nitrate supply in the soil solution. *Rumex alpinus*, restricted to nutrient- and base-rich alpine soils, is a calciophobic and nitrophilic plant species with a high absorption capacity for nitrate and potassium. Due to a selective uptake from the soil solution, *Rumex alpinus* stores mainly N, P, S, K, and Cl in the basal leaves in considerable amounts and discriminates against other elements especially calcium. As a result of an intensive accumulation of carbohydrate reserves in the below-ground phytomass and their rapid mobilisation, *Rumex alpinus* can develop immediately after snow-melt in spring and has a high ability for regrowth and a high tolerance of frequent defoliation. Therefore, *Rumex alpinus* is one of the most difficult weeds to control in mountainous regions. *Rumex alpinus* is also a host plant for vesicular-arbuscular mycorrhizal fungi.

Keywords: *Rumex alpinus*, *Rumicetum alpini*, floristic composition, soil-chemical properties, site conditions and nutrient requirements, mineral element content, nitrophilic and calciophobic plant species, nitrate reductase activity, VA-mycorrhiza

The *Rumicetum alpini* Beger 1922 is a widespread plant community in mountainous regions in Austria (e.g. HARTL & PEER 1992, KARNER & MUCINA 1993, WEISKIRCHNER 2001). This association is phytosociologically well described in many publications. In contrast, there are only few detailed ecological investigations, most of them are concentrated exclusively on the nitrogen cycle (e.g. REHDER 1982), though several edaphic site factors may be important for the incidence of *Rumicetum alpini*. Therefore, the main objectives of this study were (1) to provide data on the soil-chemical properties of *Rumicetum alpini*, (2) to provide data on the content of mineral elements in different plant organs of *Rumex alpinus*, and (3) to separate important from less important soil-chemical properties for the incidence of *Rumex alpinus* in order to forecast more accurately secondary successions.

Materials & methods

Site description

This investigation was conducted in a typical stand of *Rumicetum alpini* at the Goldeck, a mountain in the Drau valley in Carinthia in Austria, at an altitude of 1605m. The plant community has been developed at the foot of a steep north-west facing slope. Parent material of the stony, deep Cambisol is debris composed of sandstone (Buntsandstein) and limestone (Muschelkalk). The topsoil is periodically moist, the humus form is mull-like, wet moder and the soil texture is loamy sand. The small and irregular accumulation of plant residues deposited on the soil surface (0 horizon: 0–2/3cm derived from slightly to highly decomposed leaves of *Rumex alpinus*) indicates relatively favourable environmental conditions for their rapid decomposition, mineralization, and incorporation into the mineral soil. Soil water regime is periodically moist in topsoil primarily due to a long water-saturation of the alpine soil during snowmelt period. The most widespread grassland community in the study area belongs to the *Sieversio-Nardetum strictae* Lüdi 1948 (GRABHERR 1993). This plant community is restricted to acid, nutrient-poor alpine soils, and is extensively grazed by cattle without manuring or fertilization.

Methods

The topsoil of a typical stand of *Rumicetum alpini* was compared with the topsoil of an adjacent *Sieversio-Nardetum strictae*. The soil-chemical properties in the topsoil of *Sieversio-Nardetum strictae* are considered to represent the native conditions of unfertilized, acid, alpine grassland soils. Therefore, this soil, adjacent to the soil of *Rumicetum alpini* investigated, was selected as 'reference-soil'. Changes from the site-specific, native soil conditions make it possible to select important soil-chemical properties for the incidence of *Rumicetum alpini*. Of course, this comparison reflects only instantaneous conditions of the soils investigated. But, a comparison and, consequently, a characterization of a site is only possible, if soil sampling takes place during the period of highest nutrient requirements of plants.

The relevè was carried out according to the BRAUN-BLANQUET approach (BRAUN-BLANQUET 1964). Total number of vascular plant species within a homogenous investigation area of 50m² was recorded. Nomenclature of plant species follows ADLER et al. (1994).

In alpine soils 80 to 93% of the below-ground phytomass are concentrated in the uppermost 10cm of the soil (BOHNER 1998). In a *Rumicetum alpini* at an altitude of 1240m, REHDER (1982) found 77% of the below-ground phytomass in 0–5cm of soil depth. Obviously, plant roots take up most of the nutrients from the uppermost 10cm of the soil, so soil samples were collected from the 0–10cm soil layer (A horizon) at the end of May during the highest nutrient requirements of individual plant species. Soil samples were transported to the laboratory in a cooler immediately after collection. Plant roots take up most of the nutrients from the soil solution. Therefore, knowledge of the composition of soil solution is essential for assessing the nutrient availability in soil. Thus, from field-moist soil samples, a saturation extract was produced according to ÖNORM L 1092-93. For biogeochemical characterization of a plant habitat, not only ion concentrations and ratios between ions in the soil solution or in saturation extract, but also amounts of easily exchangeable and thus readily plant-available ions are important (ULRICH 1988). Therefore, from field-moist soil samples also a LiCl-extract (0.25 M LiCl-solution) was produced. Ions of both extracts were analysed by ICP and ion chromatography. Soil organic matter was determined by the WALKLEY-ARMSTRONG method. Carbonate-C was analysed by the SCHEIBLER method, and total nitrogen by a standard KJELDAHL method. Organic nitrogen was calculated as the difference between total nitrogen and mineral nitrogen. Dissolved organic carbon was determined by oxidation with $K_2Cr_2O_7$–H_2SO_4. Electrical conductivity was measured using a conductance meter and pH was determined with a pH meter. Acid-neutralizing capacity was measured by titration to pH 4.3 with HCl. Soil water content was determined gravimetrically.

In general, the nutritional status of a plant is better reflected in the mineral element content of leaves than in that of other plant organs (MARSCHNER 1998). Thus, leaves of *Rumex alpinus* were used for plant analyses in order to get informations about nutrient requirements of *Rumex* *alpinus* and furthermore, to get an indication of nutrient supply during the growing season. This is possible, because plant growth of *Rumex alpinus* seems not to be limited by any abiotic or biotic factors at the investigation area. Indeed, some elements show a preferential accumulation in the below-ground phytomass. Therefore, also the mineral element content of roots and rhizomes was analysed. Roots were not washed from soil, because during the washing procedure some elements are leached by the washing-water. Roots and rhizomes were separated from soil only with a brush and then carefully cleaned with a cleaning rag. Carbon content of the below-ground phytomass indicates no significant contamination by soil material. Healthy plants and basal leaves of *Rumex alpinus* were collected in the morning at the end of May in the rosette stage before flowering at a growing height of about 10cm from a typical stand of *Rumicetum alpini*. Plant material was dried at 80°C and digested in a mixture of nitric and perchloric acid. Mineral element content was measured by ICP. Total carbon, total nitrogen, and total sulfur in the different plant organs were determined by using an elemental analyser. Crude fibre, crude protein, crude fat, and crude ash were analysed by NIRS. Starch was determined polarimetrically, and total sugar was analysed according to FEHLING. Actual nitrate reductase activity (NRA) was assayed *in vivo* by the method described by SRINIVASAN & NAIK (1982). Vesicular-arbuscular mycorrhizal infection was estimated according to the method of VIERHEILIG et al. (1998). By comparison, also the leaves of *Veratrum album* ssp. *album* were analysed. Leaves of healthy plants were collected before flowering near the investigation area of *Rumicetum alpini*.

Results & discussion

Species composition

The *Rumicetum alpini* Beger 1922 investigated (Table 1) has developed at the foot of a steep north-west facing slope. Because of the gently sloping site (only 2° of inclination), it is a preferential place for cattle to rest and to ruminate. The plant community is floristically and physiognomically dominated by *Rumex alpinus*. *Rumex alpinus* is a tall-growing, competitive, perennial, rhizomatous plant species with high potential growth rate (KUTSCHERA & LICHTENEGGER 1992). Due to his broad, fast-growing, and horizontally orientated basal leaves, *Rumex alpinus* overshadows all other less productive plant species. Therefore, only shade-tolerant species and gap exploiters can co-exist. From an agricultural point of view, especially 'valuable' forage grasses are absent from the plant community examined. The proportion of grasses is extremely low, only *Poa supina* has a relatively high cover value. Because herbs are prevalent, *Rumicetum alpini* is characterized by an open sward with plenty bare soil. This favours gap exploiters, such as *Poa supina*, *Poa trivialis*, and *Trifolium repens*. *Rumex alpinus* is avoided by cattle. Therefore, and because of its high potential competitive ability, *Rumex alpinus* is able to dominate the vegetation, leading to a species-poor plant community. For example, the *Rumicetum alpini* investigated shows only 19 vascular plant species per 50m² homogenous investigation area, whereas the *Sieversio-Nardetum strictae* has a mean α-diversity of about 65 vascular plant species (BOHNER 1998).

Normally, Red Data Book species (NIKLFELD 1999) are absent from the *Rumicetum alpini*; species indicating nutrient-rich soils and ubiquists are prevalent. Therefore, and because of low feeding value of *Rumex alpinus*, the zoo-anthropogenic plant community has only a minor nature conservation and agricultural value (STÄHLIN & VOIGTLÄNDER 1952). Soil water regime at the investigation area is periodically moist in topsoil. Thus, indicator plants of periodically moist topsoils, such as *Deschampsia cespitosa* and *Ranunculus repens*, are relatively abundant in the

Table 1: *Rumicetum alpini* (altitude: 1605m; number of vascular plant species: 19).

	degree of coverage
Character species of *Rumicetum alpini*	
Rumex alpinus	4
Stellaria nemorum	2
Species of subalpine tall-herb communities and ruderal species	
Rumex alpestris	1
Urtica dioica	+
Alchemilla subcrenata	+
Species of alpine pastures and trampling-resistant species	
Poa supina	2
Poa alpina var. *vivipara*	+
Phleum rhaeticum	+
Species of wet and periodically wet sites	
Deschampsia cespitosa	1
Chrysosplenium alternifolium	1
Ranunculus repens	+
Alchemilla versipila	+
Species of permanent grassland	
Poa trivialis	1
Trifolium repens	1
Veronica chamaedrys ssp. *chamaedrys*	1
Taraxacum officinale agg.	+
Ranunculus acris ssp. *acris*	+
Veronica serpyllifolia ssp. *serpyllifolia*	+
Trifolium pratense ssp. *pratense*	r

Degree of coverage according to the BRAUN-BLANQUET-scale.

plant community investigated. From the surrounding vegetation (*Sieversio-Nardetum strictae* Lüdi 1948) all character species and constant companions are absent; they are replaced mainly by *Rumex alpinus* primarily through competition for light.

Soil-chemical properties

The negligible export of above-ground plant biomass due to selective rejection of *Rumex alpinus* by grazing cattle, together with a continuous input of organic matter with the faeces of cattle results in an accumulation of organic matter in the topsoil of *Rumicetum alpini* (Table 2). Subsequently, the humus accumulation leads to an increase in total nitrogen content, water-holding capacity, effective cation and anion exchange capacity (Table 2, 6, 7).

The high electrical conductivity and ionic strength as well as the high amounts of inorganic base cations (Σi_+) and inorganic anions (Σi_-) indicates an accumulation of nutrients in saturation extract (Table 3, 4), resulting both from a minor loss of nutrients by export of biomass and a continuous gain of nutrients with faeces and urine. The anion deficit in saturation extract, indi-

Table 2: Humus properties, water content, dissolved organic carbon, humus stability, and acid-neutralizing capacity.

	%			water content (mass %)		mg L^{-1}	%	meq L^{-1}
	C_{org}	N_{tot}	C_{org}:N_{tot}	swc	ws	C_{org}	hu.stab.	ANC
Rumicetum alpini	15.4	1.45	10.61	48	226	21	0.03	0.54
Sieversio-Nardetum strictae	10.3	1.09	9.46	45	195	28	0.05	0.44

swc = soil water content of field-moist soil samples; ws = soil water content at water saturation (liquid limit); hu.stab. = humus stability (dissolved organic carbon in % of C_{org}); ANC = acid-neutralizing capacity (titration to pH 4.3).

Table 3: Ion composition of saturation extract.

	μeq L^{-1}						μeq L^{-1}					μeq L^{-1}
	Ca	Mg	K	NH_4	Na	Σi_+	H_2PO_4	SO_4	NO_3	Cl	Σi_-	$\Sigma i_+ - \Sigma i_-$
Rumicetum alpini abs.	**858**	**329**	**299**	**21**	**30**	**1537**	**15**	**31**	**1085**	**87**	**1218**	**319**
%	55.8	21.4	19.4	1.4	2.0	100.0	1.2	2.6	89.0	7.2	100.0	
Sieversio-Nardetum strictae abs.	**205**	**41**	**13**	**43**	**26**	**328**	**4**	**125**	**14**	**52**	**195**	**133**
%	62.4	12.6	3.9	13.1	8.0	100.0	1.9	64.1	7.3	26.7	100.0	

Table 4: Properties and composition of saturation extract.

		μS cm^{-1}	mmol L^{-1}	μmol L^{-1}				μmol L^{-1}				%
	pH	EC	μ	Al	Fe	Mn	Si	MAN	MINBE	PTE	Σ	DA
Rumicetum alpini abs.	**6.00**	**202**	**2.01**	**8.5**	**2.7**	**1.8**	**99**	**2031**	**225**	**9**	**2265**	**1**
%								89.7	9.9	0.4	100.0	
Sieversio-Nardetum strictae abs.	**6.12**	**64**	**0.51**	**11.9**	**4.1**	**0.5**	**36**	**259**	**120**	**12**	**391**	**10**
%								66.3	30.7	3.0	100.0	

EC = electrical conductivity; μ = ionic strength; MAN = Σ NO_3-N, NH_4-N, P, S, Ca, Mg, K; MINBE = Σ Fe, Mn, Zn, Cu, B, Mo, Cl, Ni, Na, Si, Co, V, Cr; PTE = Σ Al, As, Cd, Pb; DA = H+Al+Fe+Mn in % of H+Al+Fe+Mn+Ca+Mg+K+Na (mol L^{-1}).

cating positive alkalinity, is balanced mainly by bicarbonate and organic anions (Table 3). Due to a continuous input of inorganic base cations with faeces and urine, percentage base saturation at the exchange complex is increasing, whereas exchangeable acidity is decreasing, resulting from a displacement of cation acids by inorganic base cations (Table 6). The accumulation of inorganic base cations causes an increase in acid-neutralizing capacity and, simultaneously, a reduction in the degree of acidity in saturation extract (Table 2, 4). In addition, there is a relative excess of potassium (19% of potassium saturation) and an overwhelming surplus of nitrate (Table 3). The elevated nitrate concentration with nitrate being the dominant anion, the extremely high nitrate saturation (nitrate accounts for 89% of the sum of inorganic anions on a charge equivalent basis), the low ammonium concentration, and the extremely wide molar NO_3-N:NH_4-N ratio (51) in saturation extract indicates a high rate of net nitrogen mineralization and net nitrification in the topsoil of *Rumicetum alpini* (Table 3, 5). The supply of nitrate considerably exceeds at the end of May the absorption capacity of plants and soil microorganisms despite high nitrate uptake by *Rumex alpinus*. Indeed, the acidification push, resulting from nitric acid leads only to a minor pH decrease in saturation extract (Table 4). There is no evidence of mobilization of cation acids and, consequently, there is no appreciable reduction in percentage base saturation

Table 5: Molar ratios in saturation extract.

	NO_3-N:NH_4-N	Ca:Al	Mg:Al	Ca:K	Mg:K	Ca:Mg
Rumicetum alpini	50.7	50.3	19.3	1.4	0.5	2.6
Sieversio-Nardetum strictae	0.3	8.6	1.7	8.0	1.6	5.0

Table 6: Properties and composition of LiCl-exchangeable fraction.

		meq kg^{-1}									%
	pH	Ca	Mg	K	NH_4	Na	Al	Fe	Mn	CEC_{eff}	BS
Rumicetum alpini abs.	**5.30**	**223.6**	**46.8**	**10.4**	**4.9**	**1.0**	**13.50**	**1.35**	**0.89**	**302**	
%		74.0	15.5	3.4	1.6	0.3	4.5	0.4	0.3	100.0	95
Sieversio-Nardetum strictae abs.	**4.88**	**101.5**	**9.5**	**3.1**	**4.3**	**0.9**	**15.60**	**1.09**	**0.88**	**137**	
%		74.2	6.9	2.3	3.1	0.7	11.4	0.8	0.6	100.0	87

CEC_{eff} = effective cation exchange capacity (LiCl-extract); BS = percentage base saturation.

at the exchange complex (Table 4, 6). The overwhelming excess of nitrate causes neither a negative alkalinity nor a strong reduction of acid-neutralizing capacity with a simultaneously increase in the degree of acidity in saturation extract (Table 2, 3, 4), mainly because the topsoil of *Rumicetum alpini* is in the ecologically favourable silicate buffer range.

The A horizon is well buffered against temporary acidification pushes primarily as a result of rapid and effective cation exchange reactions due to comparatively high amounts of easily exchangeable inorganic base cations (relatively high effective cation exchange capacity and percentage base saturation) and, secondarily, because of a relatively high acid-neutralizing capacity in saturation extract. The dominant buffering reaction seems to be desorption of calcium (hydrogen ions replace calcium ions at the exchange complex), leading to a high molar Ca:Al ratio in saturation extract (Table 5). As a consequence, there is no acid stress for plant roots and soil organisms due to the acidity formed during excessive net nitrification. The exchange complex is continuously replenished with inorganic base cations by nutrient release from faeces and urine, by decomposition of nutrient-rich plant residues, and by mineral weathering. Thus, there is no appreciable reduction in calcium saturation despite temporary acidification pushes, but rather an increase in magnesium and potassium saturation primarily as a result of bioaccumulation in topsoil (Table 6).

Significant leaching losses are only possible in the form of $Ca(NO_3)_2$, because *Rumex alpinus* is discriminating calcium for nutrient uptake (Table 14). In saturation extract, sulfate accounts for only 3% of the sum of inorganic anion equivalents (Table 3). Obviously, the temporary acidifying impact of nitric acid causes a significant inactivation of sulfate in the topsoil of *Rumicetum alpini* (KOLB & REHFUESS 1993). The saturation extract and the exchange complex are enriched with macronutrients and, to a lesser extent, with micronutrients and beneficial elements at the expense of potentially toxic elements (Table 4, 7). Especially the saturation extract is characterized by a disharmonic nutrient supply. The molar Ca:K and Mg:K ratios are extremely narrow as a result of excess potassium (Table 5); this favours potassium uptake by *Rumex alpinus*. The extraordinary wide molar NO_3-N:NH_4-N ratio of 51 (Table 5), the very low N_{org}:N_{inorg} ratio of 0.4 (Table 8), and the elevated nitrate concentration despite high uptake rates of nitrate by *Rumex alpinus* indicate, that the saturation extract is disproportionally enriched

Table 7: Ion composition of LiCl-exchangeable fraction.

	mmol kg^{-1}	meq kg^{-1}				mmol kg^{-1}			
	Si	H_2PO_4	SO_4	NO_3	AEC_{eff}	MAN	MINBE	PTE	Σ
Rumicetum alpini abs.	**6.7**	**1.22**	**1.37**	**2.86**	**5.45**	**155.3**	**8.9**	**4.5**	**168.7**
%		22.4	25.2	52.4	100.0	92.0	5.3	2.7	100.0
Sieversio-Nardetum strictae abs.	**5.9**	**0.40**	**0.94**	**0.07**	**1.41**	**63.8**	**7.9**	**5.2**	**76.9**
%		28.3	66.6	5.1	100.0	83.0	10.2	6.8	100.0

AEC_{eff} = effective anion exchange capacity (LiCl-extract).

Table 8: Inorganic and organic forms of nitrogen (LiCl-exchangeable fraction and saturation extract).

	LiCl-exchangeable fraction						saturation extract		
	mg 100 g^{-1}						mg 100 g^{-1}		
	N_{org}	N_{inorg}	N_{org}%N_{tot}	N_{inorg}%N_{tot}	N_{org}:N_{inorg}	NH_4-N:NO_3-N	N_{org}	N_{inorg}	N_{org}:N_{inorg}
Rumicetum alpini	32.9	10.9	2.3	0.8	3.0	1.7	1.4	3.5	0.4
Sieversio-Nardetum strictae	28.4	6.1	2.6	0.6	4.7	60.0	3.4	0.2	17.0

N_{inorg} = NH_4-N+NO_3-N.

with nitrate, and that the capacity for nitrate immobilization or plant uptake is considerably exceeded. Thus, the *Rumicetum alpini* is a nitrogen-saturated ecosystem according to ABER et al. (1989) and HOOD et al. (2003) with a high potential for nitrate leaching in form of neutral salts. Beside nitrate, also dissolved organic nitrogen is an important form of nitrogen in the topsoil of *Rumicetum alpini*. The LiCl-exchangeable organic nitrogen fraction comprises approximately 2% of the total nitrogen content, whereas the proportion of LiCl-exchangeable inorganic nitrogen fraction amounts only 0.8% (Table 8). Dissolved organic nitrogen is stronger retained at the exchange complex than nitrate and hence better protected against leaching losses. Consequently, the N_{org}:N_{inorg} ratio is much lower in saturation extract than in the LiCl-exchangeable fraction (Table 8).

Furthermore, data suggest that dissolved organic nitrogen is a component of the easily mineralizable nitrogen pool in the topsoil of *Rumicetum alpini*. The increased ionic strength and the acidification push, resulting from nitric acid, are responsible for a reduction in the amount of dissolved, organic carbon in saturation extract (EVANS 1988; TIPPING & WOOF 1990), leading to an increase in humus stability in the A horizon of *Rumicetum alpini* (Table 2). Only 0.03% of the total organic carbon content are dissolved and can be leached with seepage water. This favours the accumulation of organic matter in topsoil and leads, together with the elevated leaching losses of nitrate due to a high rate of nitrogen net mineralization and net nitrification especially of nitrogen-rich organic compounds, to a minor enlargement of the C_{org}:N_{tot} ratio in the solid phase (Table 2). Thus, soil organic matter less rich in total nitrogen is accumulating in the topsoil of *Rumicetum alpini*. Nevertheless, the C_{org}:N_{tot} ratios in topsoil are quite low at both sites.

Mineral element content and nutritive value of *Rumex alpinus*

The basal leaves of *Rumex alpinus* contain in the rosette stage a high content of crude protein and crude ash and, correspondingly, a comparatively low content of crude fat, resulting from a high uptake rate of nitrogen and other mineral elements (Table 9). The contents of crude protein,

Table 9: Nutritive value of *Rumex alpinus* and *Veratrum album* ssp. *album*.

	g kg^{-1} DM				% DM			
	CFi	CPr	CFa	CAs	St	Su	Su:St	Su:CPr
Rumex alpinus leaves	112	398	23	112	1.2	0.9	0.8	0.02
Rumex alpinus rhizomes	155	107	19	83	11.1	20.3	1.8	1.90
Rumex alpinus roots	120	111	22	70	12.9	27.1	2.1	2.44
Veratrum album leaves	157	326	44	109	n.d.	3.8	-	0.12

CFi = crude fibre; CPr = crude protein; CFa = crude fat; CAs = crude ash; St = starch; Su = total sugar; n.d. = not detectable.

Table 10: Mineral element content in *Rumex alpinus* and *Veratrum album* ssp. *album*.

	%DM			g kg^{-1} DM						
	C	N	S	P	K	Ca	Mg	MAN	MINBE	Cl
Rumex alpinus leaves	48.46	6.56	0.44	7.25	47.44	3.47	3.71	123	6.0	5.44
Rumex alpinus rhizomes	47.01	1.64	0.28	3.85	19.68	14.60	2.29	59	3.4	2.88
Rumex alpinus roots	46.58	1.64	0.26	3.30	23.73	4.65	3.28	54	4.1	3.22
Veratrum album leaves	47.96	5.37	0.33	5.61	41.68	6.15	2.41	106	0.6	0.16

MAN = Σ N, P, S, K, Ca, Mg; MINBE = Σ Fe, Mn, Zn, Cu, B, Mo, Cl, Ni, Na, Co.

Table 11: Mineral element content in *Rumex alpinus* and *Veratrum album* ssp. *album*.

	mg kg^{-1} DM													
	Fe	Mn	Zn	Cu	B	Mo	Na	Ni	Co	Cr	Se	As	Pb	Cd
Rumex alpinus leaves	128	321	59	9	23	0.8	44	0.9	0.02	0.5	0.00	0.02	0.3	0.1
Rumex alpinus rhizomes	103	205	121	4	22	1.0	71	1.1	0.09	0.9	0.00	0.02	0.6	1.0
Rumex alpinus roots	244	399	104	8	21	0.7	51	1.2	0.24	1.2	0.00	0.14	1.9	0.9
Veratrum album leaves	110	154	74	23	18	0.6	24	3.5	0.01	0.9	0.00	0.02	0.2	0.2

crude ash, and crude fat are higher in young basal leaves than in roots and rhizomes. In contrast, starch and total sugar are stored mainly in the below-ground phytomass (Table 9). Thus, roots and rhizomes serve as main storage organs of carbohydrates, whereas basal leaves in the rosette stage are preferential storage organs of protein, fat, and mineral elements. The very low content of total sugar, present in young basal leaves of *Rumex alpinus*, and the extremely low ratio of total sugar to crude protein are the result of a high nitrogen uptake, rapid protein synthesis, and intensive plant growth. Because of an increased accumulation of carbohydrate reserves in the below-ground phytomass and their rapid mobilisation, *Rumex alpinus* can develop immediately after snowmelt in spring and has a high ability for regrowth and a high tolerance of frequent defoliation. Therefore, *Rumex alpinus* is one of the most difficult weeds to control in mountainous regions.

Rumex alpinus has in the rosette stage a high nitrogen content in the basal leaves (Table 10) and stores water-soluble nitrate mainly in the roots (BOHNER et al. in prep.), indicating a high uptake rate of nitrate from the soil solution and a simultaneously inhibited nitrate reduction in the roots due to a low nitrate reductase activity in this plant organ (Table 13). *Rumex alpinus* reduces

Table 12: Ratios of individual nutrients in *Rumex alpinus* and *Veratrum album* ssp. *album*.

	C:N	N:P	N:S	N:Ca	N:Mg	N:K	K:Ca	K:Mg	Ca:Mg
Rumex alpinus leaves	7.4	9.1	14.9	18.9	17.7	1.4	14	13	0.9
Rumex alpinus rhizomes	28.6	4.3	6.0	1.1	7.2	0.8	1	9	6.4
Rumex alpinus roots	28.3	5.0	6.4	3.5	5.0	0.7	5	7	1.4
Veratrum album leaves	8.9	9.6	16.3	8.7	22.3	1.3	7	17	2.6

Table 13: Nitrate reductase activity (µmol $NO_2 \cdot h^{-1} g^{-1}$ fresh weight) in leaves of selected plant species (sampling: 30.8.2001 between 7 and 8 a.m.).

Rumex alpinus (fully expanded leaves)	**2.49**
Rumex alpinus (young leaves)	**1.55**
Rumex alpinus (roots)	**0.10**
Peucedanum ostruthium	0.99
Rumex alpestris	0.48
Arnica montana	0.12
Potentilla erecta	0.10
Rhododendron ferrugineum	0.09
Calluna vulgaris	0.07
Juniperus communis ssp. *alpina*	0.07
Vaccinium gaultherioides	0.07
Vaccinium myrtillus	0.07
Vaccinium vitis-idaea	0.05

nitrate for the synthesis of amino acids mainly in the leaves. The relatively high nitrate reductase activity especially in the fully expanded leaves (Table 13) enables an efficient utilization of nitrate for protein synthesis, being therefore the 'driving force' for a relatively large above-ground plant biomass production and rapid plant growth. The high nitrogen content and low C:N ratio in young basal leaves (Table 10, 12), the comparatively high nitrate reductase activity especially in the fully expanded leaves, the surplus of nitrate, and the extremely wide molar NO_3-N:NH_4-N ratio in saturation extract are indications of an excessive nitrate uptake by *Rumex alpinus*. Therefore, *Rumex alpinus* is a nitrophilic plant species with the ability to utilize large amounts of nitrate. The opposite may be true for dwarf-shrubs, suggested by the low nitrate reductase activity in their leaves (Table 13). Therefore, species of *Ericaceae* are restricted to soils poor in nitrate-nitrogen.

Rumex alpinus has in the rosette stage a very low calcium content in the basal leaves (Table 10). Obviously, the translocation of calcium from the roots and rhizomes to the basal leaves is strongly restricted. Therefore, and due to the high content of water-soluble oxalate together with a comparatively low content of water-soluble malate in the basal leaves (BOHNER et al., in prep.), *Rumex alpinus* can be considered as a calciophobic plant species according to HORAK & KINZEL (1971) and KINZEL (1982). The basal leaves of *Rumex alpinus* contain in the rosette stage a relatively high content of macronutrients (Table 10), resulting primarily from a high uptake rate and accumulation of nitrogen and potassium. An increased potassium content in

Table 14: Transfer factor of selected elements (transfer factor = content in plant/concentration in soil, LiCl-exchangeable fraction).

R. alpinus	N	P	S	K	Ca	Mg	Fe	Mn	Zn	Cu	B	Mo	Na	Ni	Co	Cr	As	Cd	Pb
leaves	602	192	200	117	0.8	6.5	3.4	13.1	12.8	11.8	41.3	7.1	1.9	3.5	0.2	2.1	0.1	0.3	0.4
rhizomes	151	102	125	48	3.3	4.0	2.7	8.4	26.1	5.3	39.9	8.7	3.1	4.3	0.8	3.9	0.1	2.4	1.0
roots	151	87	117	58	1.0	5.8	6.5	16.3	22.5	10.4	37.9	5.9	2.2	4.7	2.0	5.5	0.6	2.2	3.0

Table 15: Degree of mycorrhization (%) of selected plant species.

	n	date of sampling	VAM %	V %
Homogyne alpina	10	16.7.	35	4
Potentilla erecta	8	16.7.	32	9
Rumex alpinus	**10**	**9.6.**	**30**	**13**
Arnica montana	10	16.7.	29	9
Gentiana acaulis	10	16.7.	27	7
Veratrum album ssp. *album*	10	9.6.	23	15
Rumex alpestris	8	26.7.	21	11
Avenella flexuosa	10	26.7.	20	19
Stellaria nemorum	6	9.6.	18	18
Nardus stricta	10	16.7.	17	11
Phleum rhaeticum	10	26.7.	15	15

n = number of plants investigated; VAM % = percentage VAM colonization; V % = variation coefficient in %.

the leaves of *Rumex alpinus* was also observed by KROPFITSCH (1986) and STEMMER & PEER (1993). Potassium enrichment in basal leaves of *Rumex alpinus* is responsible for the high water content in this plant organ. The amounts of micronutrients and beneficial elements in basal leaves of *Rumex alpinus* are elevated too, particularly those of chloride and manganese (Table 10, 11).

Some mineral elements (Ca, Fe, Mn, Zn, Mo, Na, Ni, Co, Cr, As, Pb, Cd) are present in higher quantities in the below-ground phytomass than in the young basal leaves (Table 10, 11), indicating an inhibited translocation to the basal leaves and/or a specific storage in the below-ground phytomass. Especially rhizomes are characterized by an extraordinary high content of calcium, zinc, and sodium during the rosette stage. Apart from nutrient contents ratios of nutrients in plant tissue are important, indicating nutrient imbalances in plant organs. Calciophobic plant species, such as *Rumex alpinus*, are characterized by a relatively low Ca:Mg and high K:Ca ratio in their basal leaves (Table 12). The observed N:P and N:S ratios in the basal leaves of *Rumex alpinus* are within the normal range in plant tissues, indicating also a comparatively high demand for phosphorus and sulphur. In contrast to basal leaves, roots and rhizomes of *Rumex alpinus* are particularly nitrogen-poor plant organs during the rosette stage (Table 10, 12). Also REHDER (1982) observed a markedly lower nitrogen content in the roots than in the above-ground plant organs. By comparison, grass roots grown without fertilizer nitrogen generally have a nitrogen content of about 1,0% or less and C:N ratios of around 40:1 to 50:1 (WHITEHEAD 1986). Therefore, roots and rhizomes of *Rumex alpinus* can be considered comparatively nitrogen-rich. Consequently, there may be no substantial microbial immobilization of soil inorganic nitrogen during the decomposition of below-ground phytomass of *Rumex alpinus*. The transfer factor indicates, that *Rumex alpinus* stores mainly N, S, P, and K in young basal leaves in considerable amounts due to a selective uptake from the soil solution and discriminates against other elements especially calcium (Table 14). Nitrogen and sulphur are necessary for protein synthesis. Phosphorus is an essential structural element (nucleic acids) and important for the energy transfer in plants and thus also required for starch synthesis (MARSCHNER 1998). Potassium is the major osmoticum in guard cells and therefore of utmost importance for the water status of plants (MENGEL & KIRKBY 2001). *Rumex alpinus* has a high potassium requirement primarily for the regulation of turgor due to his large, broad basal leaves. Also chloride is an important osmoticum in plants and acts as a nonmetabolized counter-ion to potassium in order to maintain electroneutrality in the leaf cells (SMITH et al. 1987, FLOWERS 1988). The high chloride requirement of *Rumex alpinus* (Table 10) may be a consequence of the inability to synthesize sufficient quantities of malate in his leaf cells in order to act as a counter-ion to potassium. Since calciophobic plant species are not able to accumulate high amounts of calcium malate in their leaves (KINZEL 1982), they require obviously mainly KCl as an osmoticum. Thus, *Rumex alpinus* is a nitrophilic plant species with high demand for N, P, S, K, and Cl.

Vesicular-arbuscular mycorrhiza

Roots of *Rumex alpinus* are colonized by vesicular-arbuscular mycorrhizal (VAM) fungi (Table 15). All plant species investigated show either a medium or a low degree of colonization of their roots by VAM fungi and there is no significant difference in percentage VAM colonization when comparing plant species adapted to acid, nutrient-poor soils and plant species indicating nutrient-rich soils. It can be concluded, that *Rumex alpinus* and some other character species of the *Rumicetum alpini*, such as *Stellaria nemorum*, are host plants for mycorrhizal fungi despite nutrient-rich soil.

Conclusions

On typically, alpine pastures, characterized by a continuous cattle grazing without grazing management during the grazing season, there is a considerable transfer of nutrients and organic matter between different ecosystems by grazing cattle. Through cattle grazing nutrients (mainly nitrogen and potassium) and organic matter are continuously transferred from slopes towards flat areas where cattle rest and ruminate (SPATZ 1994). On preferential cattle resting-places, organic matter and nutrients (mainly nitrate and potassium) are accumulating in topsoil primarily due to enhanced external inputs with faeces and urine, gradually leading to a nitrogen-saturated ecosystem. Nitrogen and potassium are the primary nutrients transferred between different sites by grazing cattle, because of their highest contents in the above-ground plant biomass (highest removal) and their considerable release from faeces and urine. The nutrient enrichment in topsoil, resulting from a permanent disequilibrium between import and export of nutrients by grazing cattle primarily favours *Rumex alpinus*, because this nitrophilic plant species is best adapted to the temporary surplus of nitrate and the disharmonic nutrient supply in the soil solution, resulting from an excess of nitrate and potassium. Due to the absence of high-yielding, competitive fodder grasses as a result of unfavourable climatic conditions in mountainous regions and due to its high competitive ability as well as intensive vegetative propagation in the case of suitable site conditions, *Rumex alpinus* is able to create a stable but species-poor, productive permanent community dominated by some few nitrophilic herbs. The long-term consequence of this redistribution of nutrients within the grazing area is a strong heterogeneity in soil nutrient content and plant species composition, leading to an increase in β- and γ-diversity on alpine pastures. An abundant incidence of *Rumex alpinus* not only requires an increased supply of all essential plant nutrients, except for calcium, during the growing season, but also a relatively high percentage base saturation and acid-neutralizing capacity in soil as a protection against acid stress. This can be concluded from unfertilized acid alpine soils (soils in the Al and/or Fe buffer range), which are characterized by a distinct nutrient and acid stress, resulting from a disharmonic composition of the soil solution and the exchange complex. Acid stress is the primary edaphic site factor limiting plant growth, followed by the supply of inorganic nitrogen and/or phosphorus. In contrast, the supply of potassium is rarely the limiting factor in very acid unfertilized alpine soils (BOHNER 2002, 2005). The humus form in topsoil of *Rumicetum alpini* suggests that, the large quantities of nutrient-rich above-ground and below-ground plant residues primarily of *Rumex alpinus* are decomposed easily, leading to a large and rapid nutrient cycling inside the ecosystem. Once established, the high productivity and longevity of the phytocoenosis is mainly the result of this short-closed ecosystem-internal nutrient cycle. The most important character species of *Rumicetum alpini*, *Rumex alpinus*, is an indicator species (bioindicator) of soils rich in nitrate and potassium. *Rumex alpinus* is a calciophobic and nitrophilic plant species with a high absorption capacity for nitrate and potassium. Because of a selective uptake from the soil solution, *Rumex alpinus* stores mainly N, P, S, K, and Cl in the basal leaves in considerable amounts and discriminates against other elements especially calcium. Due to the enhanced requirement for N, P, S, K, and Cl, *Rumex alpinus* is restricted to nutrient- and base-rich alpine soils. As a result of an intensive accumulation of carbohydrate reserves in the below-ground phytomass and their rapid mobilisation, *Rumex alpinus* can develop immediately after snowmelt in spring, and has a high ability for regrowth and a high tolerance of frequent defoliation.

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