ECOMONT: New Concepts for Assessing Ecological Effects of Land Use Changes on Terrestrial Mountain Ecosystems at an European Scale

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Synopsis

As a contribution to the Terrestrial Ecosystem Research Initiative (TERI) within Framework IV of the EU, ECOMONT aims at investigating ecological effects of land-use changes in European terrestrial mountain ecosystems. ECOMONT is carried out by nine European partner teams in six composite landscapes in the Eastern Alps, the Swiss Alps, the Spanish Pyrenees and the Scottish Highlands. ECOMONT focuses on an analysis of structures and processes in the context of land-use changes, scaling from the leaf to the landscape level. The following research topics are being investigated: Spatial distribution of vegetation and soil in the composite experimental sites; physical and chemical soil properties, SOM status and turnover; canopy structure; water relations of ecosystems and hydrology of catchment areas; microclimate and energy budget of ecosystems; gas exchange of single plants, ecosystems and gas exchange between the composite experimental sites and the atmosphere; potential risks through land-use changes. Based on first results, the following conclusion can be drawn: While there is the general trend in all investigated landscapes that upon abandonment of management open grassland changes to dwarf shrub communities and to woods, regional differences in specific patterns of vegetation changes, which are related to land-use history, geology, altitude and exposure, can be observed. Abandonment leads to an accumulation of dead organic matter on the soil surface and hence to soil physical and soil chemical changes. Land-use induced changes in the uppermost layer of the soil profiles may occur within decades, whereas changes in deeper soil layers may take thousands of years. Traditional land-use in mountain areas causes a high number of plant species, which declines with abandonment but also with intensification (fertilization). Land-use induced changes in the vegetation structure decisively influence the ecosystem processes (microclimate, gas exchange with the atmosphere, primary production, decomposition). Abandonment leads to a decrease in soil respiration, which is coupled with a decreased litter decomposition and a decreased nutrient availability. Abandonment leads to a decrease of canopy photosynthesis, which is the result of decreased nutrient availability on photosynthesis, changes in species composition, as well as an increasing proportion of photosynthetically inactive components of the phytomass.

Alpine Ecosystems, land-use changes, CO_2- and H_2O-fluxes, landscape ecology

1 Introduction

Presently, in the Alps land-use changes in agriculture and forestry are occurring rapidly. Land-use changes cause long-lasting changes in the spatial structure of plant canopies, species composition and interactions, soil organic matter (SOM) status and turnover, and biogeochemical cycles, such as of CO_2, H_2O and nutrients. In mountain regions these changes in ecosystem processes can also cause a considerable increase of potential risks (danger of torrents, snow gliding and avalanches, increased development of patches of bare soil and unstable slopes). As a contribution to the Terrestrial Ecosystem Research Initiative (TERI, Framework IV for research and technological development of the European Union) the project ECOMONT aims at investigating the ecological effects of agriculture and forestry induced land-use changes in the mountains. Within this project the effects of a reduction of land-use and abandonment, but also an intensification and reforestation of hay meadows and pastures above and below the timber line are to be investigated.

2 Research sites

Six composite landscapes are investigated in the subalpine belt of different European mountain regions (see Fig. 1). Three landscapes are situated along a South/North-transect across the Eastern Alps (»Monte Bondone« near Trento, geologically dominated by limestone; »Passeier Valley«, South Tyrol, geologically dominated by silicate; »Stubai Valley«, North Tyrol, geologically dominated by silicate with

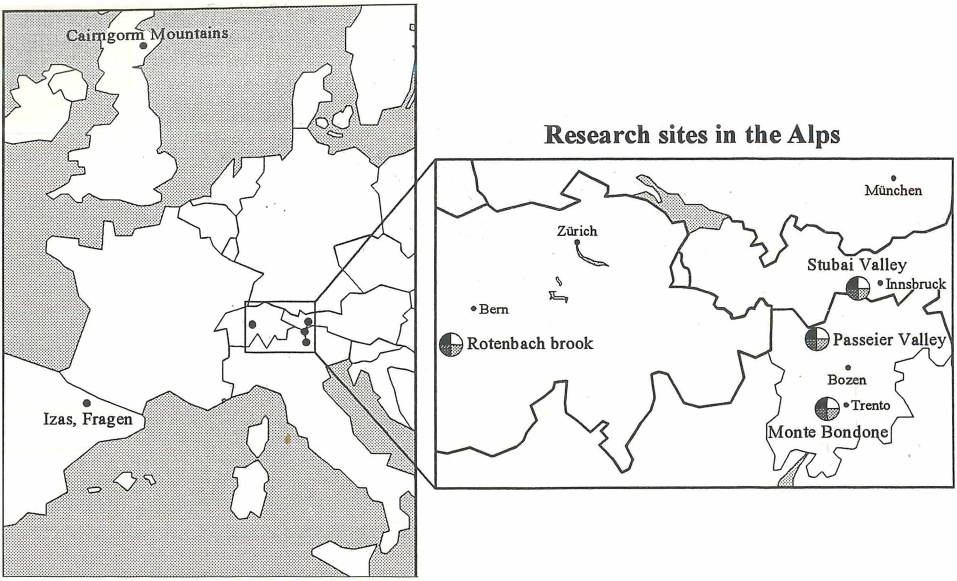

Fig. 1
ECOMONT research sites in the Alps, the Pyrenees and the Scottish Highlands.

transitions to limestone), and a fourth site is the catchment Rotenbach brook in the Swiss Alps, geologically dominated by ›Flysch‹. In order to consider adequately the different background conditions of mountain ecosystems in Europe (exposure, geology, climate, socio-economy) and thus to be able to draw conclusions for other parts of Europe, investigations in the Spanish Pyrenees and the Scottish Highlands are also included. The two pilot research areas »Passeier Valley« and »Stubai Valley« offer an important advantage for the application of the research results, because they are situated in Objective-5b-Regions of the EU. In these regions assistance for regional projects for the improvement of the rural infrastructure will be carried out within the EU-programme INTERREG II in the next five years (Cernusca & Tappeiner 1997).

3 Methods

In each ECOMONT study site, comparative, multidisciplinary integrated ecosystem studies are conducted on differently managed and abandoned ecosystems (meadows, pastures, abandoned areas, dwarf shrub communities and forests). Table 1 shows the 12 research topics and the contributing partner teams. ECOMONT attempts to integrate two different basic approaches: A landscape ecological approach, including investigations of vegetation dynamics, soil properties and agricultural ecology along different successional stages from intensively managed to abandoned ecosystems (research topics n°1, n°2, n°10, n°11), and secondly, integrated ecosystem studies including comparative investigations of different successional stages within the composite experimental sites. Following a bottom up approach, the gas exchange (CO_2, H_2O, and related trace gases) of single plants, functional plant groups, ecosystems and composite landscapes is investigated (research topics n°6, n°7, n°8). This up-scaling approach combines field measurements and mathematical modelling (research topic n°12). At each level of integration the modelled results are validated by field measurements.

3.1 Spatial distribution of vegetation and soils

The large-scale mapping of vegetation and soils is the basis for scaling up the results of the detailed ecosystem analyses to the landscape level. Furthermore, the maps serve for calibrating and verifying the remote sensing data. For phytosociological investigations the relevé method is used. The syntaxonomical classification is made with the classification programme SORT. The phytosociological nomenclature is based on Mucina & al. (1993), Dietl (1995). A further ecological characterization is made on the basis of the ecological indicator values and an estimation of total vegetation cover. For the mapping and characterization of soils, important soil parameters are recorded in the field, e.g. soil type, profile description (geology,

Table 1
Research topics of ECOMONT and the contributing partner teams.

Research topics of ECOMONT
1. Spatial distribution of vegetation and soil in the composite experimental sites
2. Physical and chemical soil properties, SOM status and turnover
3. Canopy structure, primary production
4. Water relations of ecosystems and catchment areas
5. Microclimate, energy budget of ecosystems
6. Gas exchange of single plants and ecosystems
7. Gas exchange between the composite experimental sites and the atmosphere
8. Population and plant biological studies
9. Potential risks through land-use changes
10. Geographical Information System (GIS)
11. Remote sensing
12. Modelling activities integrating from the plant level to the ecosystem and landscape level.

Contributing Partner Teams
- Institut für Botanik, Universität Innsbruck (A) (coordinator)
- Institute of Terrestrial Ecology (ITE), Banchory, Kincardineshire, Scotland (GB)
- Institut für Terrestrische Ökosystemforschung (BITÖK), Universität Bayreuth (D)
- Europäische Akademie Bozen (EAB), Bozen (I)
- Centro di Ecologia, Monte Bondone (CEA), Trento (I)
- Instituto Pirenaico de Ecologia (IPE), Jaca (E)
- Paul-Scherrer-Institut (PSI), Villigen-PSI (CH)
- Forschungsanstalt für Agrarökologie und Landbau (IUL), Bern-Liebefeld (CH)

soil water regime, soil horizon depths, soil moisture, soil colour, consistency, soil texture, amount and type of humus, pH, soil structure, maculation, concretation, rooting density).

3.2 Canopy structure, primary production, decomposition

Canopy structure is analysed by indirect methods (hemispherical lens measurements) and by direct methods (stratified clipping and hand inclinometer). In the forest stands leaf area index, leaf distribution and mean foliage inclination angle are measured with the CI-100 Plant Canopy Analyser, equipped with a digital camera with a »fish-eye« lens providing a detailed scan of the plant canopy. In the grassland communities canopy structure is analysed by the stratified clipping method, which consists of harvesting layer-wise the above-ground vegetation of a representative plot, and measuring separately the dry mass of stems, leaves, inflorescences or fruits and dead plant material for each species in each layer. Leaf and total plant area index are calculated from measurements of the area of the leaves and the other plant parts of each species per layer using a leaf area meter (LI-3100, LI-COR Corp., Lincoln USA). Field measurements of leaf and stem inclination of the dominant species in each layer are made with a hand inclinometer. Primary production is analysed using the harvesting method. This involves measurements of biomass, necromass and litter throughout the year. Litter decomposition is investigated by the litter bag technique (Tappeiner & Cernusca 1996).

3.3 Gas exchange processes

Measurements of the fluxes of CO_2 and water vapour between the plant cover and the atmosphere are conducted at the levels of leaves and plant species, of ecosystems and of landscapes. Ecophysiological investigations on up to 200 different plant species are being conducted in order to understand how plant species are affected by changes in land-use, how plant species interact with the surrounding canopy and how they affect and contribute to ecosystem gas exchange processes. Net photosynthesis and stomatal conductance are measured in the field with fully climatized CO_2/H_2O porometers (Bahn & Cernusca 1998). At the ecosystem level the atmospheric gas exchange is measured using two different micro-meteorological approaches: Gas exchange of grassland and dwarf shrub ecosystems is monitored by means of the Bowen-ratio energy-balance method (Tappeiner & Cernusca 1996). In forest stands towers of 30 m height are used to carry sonic anemometers and the fast responding water vapour and temperature sensors to measure the CO_2 and H_2O fluxes by means of the Eddy-correlation method. The evaporative water loss of selected trees is determined by means of the xylem sap flux measurements in combination with micro-meteorological data (Köstner & al. 1992). Release of CO_2 from the soil is measured in situ by IRGA techniques. At the landscape level the gas exchange (CO_2, H_2O, and related trace gases) between the composite landscape and the atmosphere is measured using a SCIDAR/DOAS system in combination with an equipped aircraft flying at a constant height above the landscape (Graber & al., 1998): A virtual triangular volume is defined over the composite landscape. The horizontal fluxes crossing the boundaries of the box are determined by means of a combination of the scintillation anemometry (SCIDAR) and the open path absorption spectroscopy (DOAS). The upper boundary of the virtual box is given by the flight height of an motorglider (flying about 50 m above the ground) equipped with instruments for measuring NO_2, O_3, temperature, humidity, air pressure, wind speed and direction.

3.4 Water relations and hydrological balance of ecosystems, catchments

Precipitation amount and intensity are measured using tipping bucket raingauges, soil water content is determined by Time Domain Reflectometry (TDR) and soil water potential by tensiometers which also quantifies the pore water pressure. The simultaneous determination of profiles of soil water content and potential allows an in-situ description of the characteristic water content – potential curve; this curve is also determined by laboratory methods on soil cores. Evapotranspiration of grassland and dwarf shrub ecosystems is monitored by lysimeters, as well as by the energy-balance-Bowen-ratio-method (see also 3.3). Run-off from defined experimental plots is monitored by means of a seesaw system. Discharge of the catchment is monitored by means of a triangular shaped measuring weir.

3.5 Integrative modelling activities

A hierarchy of models (Tenhunen 1998, Cernusca & al. 1998) scaling up from the individual leaf or branch to the stand and further to the landscape (catchment) level is used to quantify controls on CO_2 and water vapour fluxes within the Alpine ecosystems and landscapes. Steady-state gas exchange response of leaves (needles) at any particular point in the canopy is calculated as the response of photosynthesis and stomatal conductance to photosynthetic photon flux density, leaf temperature, wind speed and the partial pressures of CO_2 and H_2O. The photosynthesis model is that of Farquhar et al. (1980), modified by Wohlfahrt & al. (1998). Canopy gas exchange of forest ecosystems is simulated using the model STANDFLUX (Falge & al. 1996). To account for the large number of species in mountain grassland ecosystems (up to 90 in a recently abandoned ecosystem, cf. Cernusca & al. 1992), a multi-species canopy model is being designed which considers both structural and physiological diversity. Light attenuation is assessed with a one-dimensional model which takes into account multiple scattering of light beams (Royer & al. 1998), which has been found to contribute to about 30% to the radiation field within grassland canopies. Non-uniform distribution of leaves within the canopies is accounted for by a distribution factor, which has been shown to be of significant relevance (Tappeiner & Cernusca, 1996). At the landscape scale PROXEL (process-based pixel), a soil-vegetation-atmosphere gas exchange model, which is intentionally kept simple, in order to be incorporated into GIS, is used. Control of CO_2 and water vapour gas exchange within PROXEL is described using a biologically-based BIGLEAF (Falge & al. 1996). Soil water content is calculated with a multiple layer budget approach, and is applied to determine above-ground gas exchange by a coupling factor, which influences the degree of stomatal opening.

3.6 Spatial models and the development of landscape scenarios

Finally, additional modelling approaches of high ecological relevance must be mentioned: Spatial models that are constructed together with remote sensing activities (research topic n°11) offer a considerable potential for extrapolation of the results, i.e., the remotely sensed data should aid application of the models at additional sites. The stepwise development of this research at multiple sites permits us jointly to investigate extrapolation potentials. Additionally, the spatial models are examined with respect to the prediction of ecological risks. Risks due to soil movement and avalanches (work package n°9) are related to topography, soil properties and vegetation. Spatial simulations of the dynamics of ecosystem water balance are studied with respect to these potential risks. A first GIS-based model predicting land-use induced plant-cover changes has been developed and tested for the ECOMONT site »Passeier Valley« (Tappeiner & al. 1998).

4. First results and discussion

4.1 Impact of land-use on plant cover and soils

Fig. 2 (middle) shows a typical example of the change of vegetation communities following land-use change in the Eastern Alps on silicate (composite experimental site at Passeier Valley, 1600 – 2000 m a.s.l.). Up to the mid-seventies, the research area in the Passeier Valley was characterized by hay meadows with a low degree of management. Since the construction of a forest road 20 years ago some meadows have been

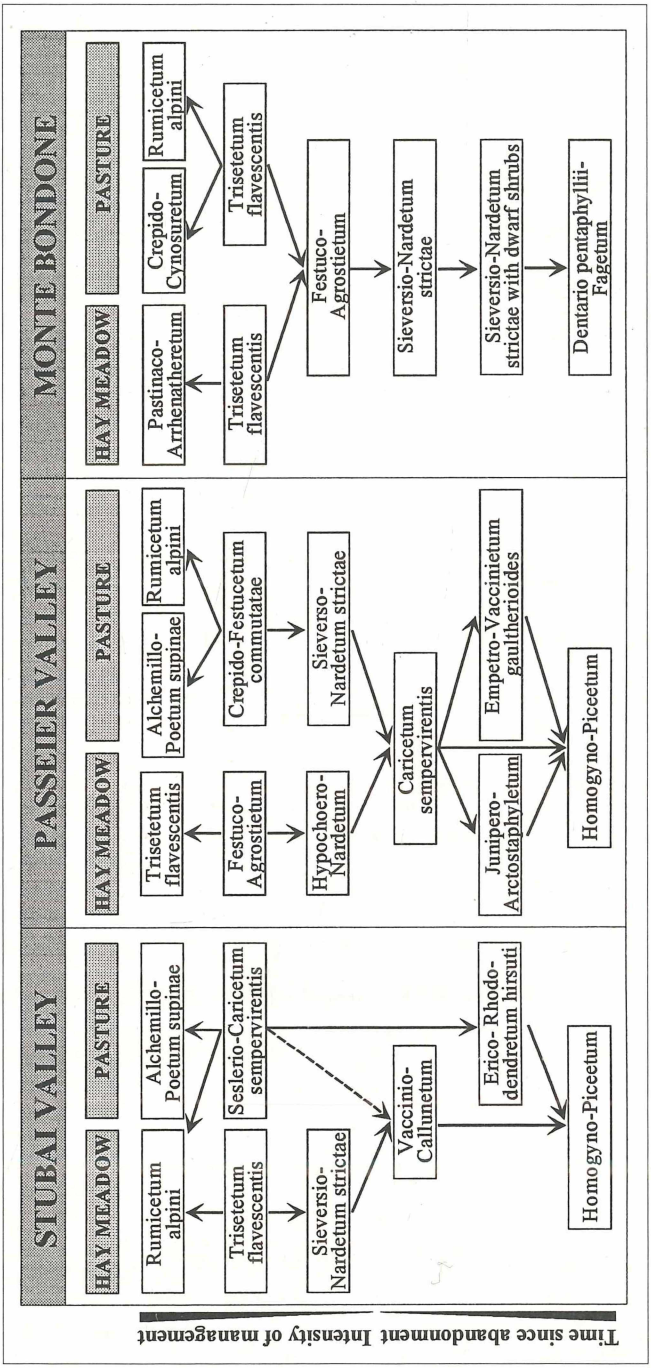

Fig. 2
Effects of land-use on the vegetation composition in the Eastern Alps (left: on limestone, composite experimental site at Stubai Valley, 1600–2000 m a.s.l.; middle: on silicate composite experimental site at Passeier Valley, 1600–2000 m a.s.l.; right: on limestone, composite experimental site at Monte Bondone, 1600 m a.s.l.). After Tasser & al. 1998.

used more intensively, while others have been abandoned (50%) or transformed into pastures (15% of the area). Increased fertilization and irrigation have transformed smaller parts of the hay meadows to Trisetetum flavescentis. When the intensity of management decreases, the vegetation community of the hay meadows changes from Festuca-Agrostietum to Hypochoero-Nardetum and Caricetum Sempervirentis. Where meadows or pastures have been abandoned for more than five years dwarf shrubs start dominating the communities (Junipero-Arctostaphyletum, Empetro-Vaccinietum gaultheroides). The climax vegetation of this successional sequence is a spruce forest (Homogyno-Piceetum).

A typical example of the change of vegetation communities following land-use change in the Eastern Alps on limestone is shown in Fig. 2 (left) (composite experimental site at Stubai Valley, 1600–2000 m a.s.l.). In the research area in the Stubai Valley more intensively used meadows (Trisetetum flavescentis) are cut once a year, fertilized and grazed later in summer. In meadows mowed only every two years, Nardus stricta and dwarf shrubs get established (Sieversio Nardetum strictae). Pastures on limestone belong to the association of Seslerio-Caricetum sempervirentis. Where trampling impact due to higher grazing pressure from cattle increases an Alchemillo-Poetum develops. Resting places for animals are dominated by Rumex alpinus (Rumicetum alpini). When abandoned, meadows and pastures change to dwarf shrub communities (Vaccinio-Callunetum). The climax vegetation on limestone is sometimes a Erico-Rhododendretum hirsuti, in most cases, however, a subalpine spruce forest (Homogyno-Piceetum).

At the composite experimental site Monte Bondone (Fig. 2, right), the southernmost research area in the Eastern Alpine transect (geology: limestone), a major part of the grassland belongs to the association Sieversio Nardetum strictae, which is observed on pastures and hay meadows with a low degree of management. Where land-use is intensified, pastures develop to Crepido-Cynosuretum, hay meadows change to communities belonging to the Trisetetum flavescentis and the Pastinaco-Arrhenateretum. When pastures and hay meadows are abandoned dwarf shrubs and young trees invade. The climax vegetation on Monte Bondone is a beech forest (Dentario pentaphyllii-Fagetum), which in a smaller area has been transformed by forestry measures into a larch wood.

Changes in land-use are connected with long-lasting changes in the structure, functioning and dynamics of the involved terrestrial mountain ecosystems. Above all, changes in species composition and performance, as well as in species competition and interaction are occurring. Land-use has a decisive influence on the number of species in differently managed alpine grassland-ecosystems. The number of plant species is highest on lightly-managed meadows. The species number declines with intensification, but also with abandonment.

Further consequences of land-use changes are changes in soil organic matter, status and turnover. Abandonment leads to an accumulation of necromass on the soil surface, and soil organic matter increases (Bitterlich & Cernusca 1998, in this volume). In this context it should be pointed out that changes in the uppermost layer of the soil profiles may occur within decades, whereas changes in deeper soil layers might need even more than thousands of years.

4.2 Impact of land-use on the energy regime and the gas exchange processes

Closely connected with changes in the plant cover are also changes in the canopy structure (Tappeiner & al. 1998) and changes in ecosystem processes, as for example in the energy regime and the gas exchange processes of ecosystems. Fig. 3 shows the energy-regime and the gas exchange processes of differently managed grassland-ecosystems. The results correspond with earlier investigations of our group (Cernusca 1991, Tappeiner & Cernusca 1991, 1994, 1996), showing that changes in canopy structure have a decisive influence on the distribution of the absorbed radiation energy (Rn). Reduced management and abandonment leads to a reduction of evapotranspiration (LE), and to a corresponding increase of the sensible heat fluxes to the atmosphere (H). Abandonment leads to an increasing accumulation of dead plant material within the canopy, and as a consequence a larger part of the absorbed radiation energy is converted into sensible heat.

Evapotranspiration calculated by means of the Bowen-ratio energy-balance method agreed well with measurements by means of lysimeters. For the time interval May 28th to October 14th 1997 (140 days) lysimeters showed an evapotranspiration of 395 for the intensively managed hay meadow, of 364 for the pasture and of 362 l m-2.for the abandoned area.

The observed reduction of canopy-photosynthesis (Ac) in the abandoned areas is partly the consequence of the mentioned accumulation of attached dead plant material, absorbing light without any contribution to canopy photosynthesis. Another very important explanation for the observed decrease of the canopy photosynthesis after abandonment could be provided by detailed ecophysiological investigations. As measurements of Bahn & al. (1998) have shown, the photosynthetic capacity of species decreases with decreasing management (Table 2). The reason for this is twofold: Firstly, on the abandoned area a number of species get established that display a lower photosynthetic capacity per se, such as shrubs and dwarf

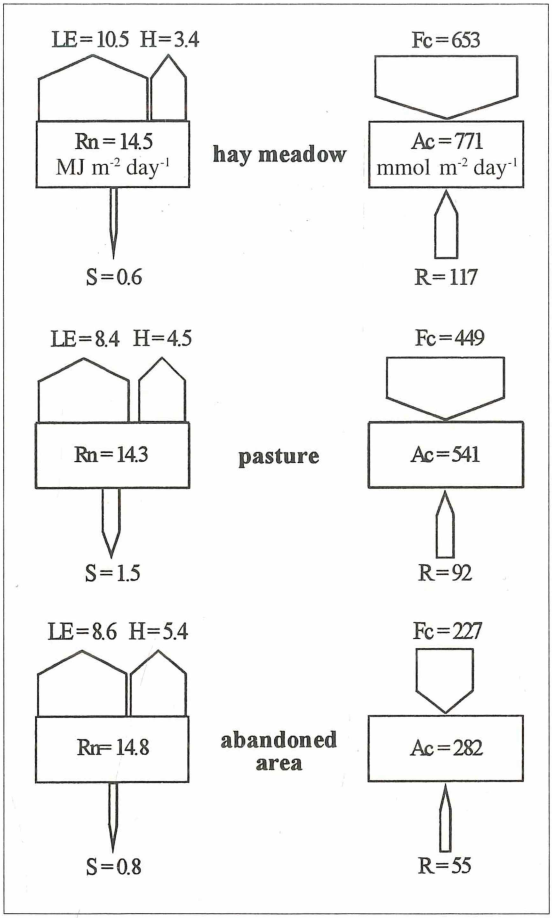

Fig. 3

Effects of land-use on the energy regime and on the daily CO_2 fluxes at the ECOMONT site »Monte Bondone« (after Tappeiner & Cernusca 1998). (LE) evapotranspiration, (H) sensible heat flux to the atmosphere, (Rn) absorbed radiation energy, (S) sensible heat flux into the soil, (Ac) canopy photosynthesis, (Fc) CO_2 flux from the atmosphere to the canopy, (R) CO_2 release from the soil (soil respiration).

shrubs. Secondly, decreasing land-use reduces the nitrogen availability for plants, which frequently results in lower leaf nitrogen concentrations on abandoned areas as compared to the intensively managed areas. Plant species, which grow in ecosystems under different land-use, displayed distinctly lower leaf nitrogen contents on an abandoned area as compared to a hay meadow (Table 2).

Beside photosynthesis and primary production the CO_2-release from the soil (R) plays an important

Table 2

Mean values (± standard error) of photosynthetic capacity (A), dark respiration rate (R), quantum use efficiency (QUE) and leaf nitrogen content (N). Gas exchange parameters were calculated with the parameterized leaf model (Wohlfahrt et al. 1998) and refer to a leaf temperature of 20°C, an ambient CO_2 partial pressure of 35 Pa and an ALVPD of 13.7 Pa kPa-1. The investigated species (total number = 31) were grouped to their occurence on the differently managed sites (after Bahn & al. 1998).

Land-use	n	A	R	QUE	N
		umol m^{-2} s^{-1}	umol m^{-2} s^{-1}	mol mol^{-1}	mg g^{-1}
Abandoned areas	8	8.3 ± 1.6	1.4 ± 0.2	0.037 ± 0.001	20.1 ± 1.0
Meadows	17	11.7 ± 1.0	1.5 ± 0.2	0.039 ± 0.001	31.9 ± 2.1
Pastures	6	10.5 ± 1.4	1.8 ± 0.3	0.039 ± 0.002	25.8 ± 2.3

role in the CO_2-gas exchange of the landscape. Measurements of soil respiration showed a clear dependency on soil temperature, soil water content and content of organic matter in the soil. In all investigated ecosystems soil respiration reached the highest values in pastures. In meadows, however, the soil respiration was reduced by 15 to 30% and in the abandoned grassland by 30 to 50%. A reduced nutrient content in the soil as well as a reduced biomass of the micro-organisms are responsible for the reduced soil respiration in the abandoned areas. The result is a reduced decomposition activity of the microorganisms which also corresponds well with a decrease of litter decomposition measured by the litter bag technique. In all investigated alpine pastures a steep increase of soil respiration with increasing soil temperatures could be observed. These results for the alpine pastures are of course of specific interest in context with the expected global warming.

5 Conclusions

Based on results of ECOMONT and former ecosystem research (Cernusca 1991), the following conclusions can be drawn:

Land-use has a decisive influence on diversity and ecological complexity at all levels and scales (species, ecosystems, landscapes). Traditional land-use in mountain areas causes a high number of plant species, which declines with abandonment but also with intensification (high fertilization). Abandonment leads to an accumulation of dead organic matter on the soil surface and hence to soil physical and soil chemical changes. Land-use induced changes in the uppermost layer of the soil profiles may occur within decades, whereas changes in deeper soil layers may take thousands of years. Land-use induced changes in the vegetation structure decisively influence the ecosystem processes (microclimate, energy regime, gas exchange with the atmosphere, primary production, decomposition). Abandonment leads to a decrease in soil respiration, which is coupled with a decreased litter decomposition and a decreased nutrient availability. Abandonment leads to a decrease of canopy photosynthesis, which is the result of decreased nutrient availability on photosynthesis, changes in species composition, as well as an increasing proportion of photosynthetically inactive components of the phytomass (attached dead plant material).

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