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"Seed propagation of indigenous species and their use for restoration of eroded areas in the Alps"

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Seed Propagation of Indigenous Species and their Use for Restoration of Eroded Areas in the Alps (Alperos)

Executive Summary

Within the whole alpine area, thousands of hectares are machine graded or affected every year, e.g. by construction of ski runs, ski lifts, tourists infrastructure and roads. Restoration of damaged areas in high altitudes is often done with an inadequate combination of technical and biological measures. Cheap application techniques and cheap seed mixtures containing species that are not adapted for high altitudes are, up to now, standard methods. The resulting ecological and economical damage is considerable: soil erosion, increased surface runoff, degradation of the vegetation, need for frequent reseeding and constant fertilising, flora falsification, expensive maintenance. Due to this situation, especially the economically important winter and summer tourism has got a very negative image.

The research project "Seed Propagation of Indigenous Species and their Use for Restoration of Eroded Areas in the Alps" (FAIR CT98-4024, short title "Alperos"), supported by the EU, was carried out from 1999 to 2002. At 8 different locations at altitudes between 1.200 and 2.300 meters, trials were set up and assessed during the last four years. The necessary demands on application techniques in order to avoid erosion during the first two growing seasons as well as demands on seed mixtures in order to achieve the development of a dense, sustainable vegetation at different altitudes and under different site conditions were assessed. The specific climatic conditions with its limiting effects on growth and biomass production of plants, that are increasing with altitude, were observed. Different parameter were used to describe the ecological value of plant stands depending on the seed mixture used. To quantify the possible improvements, a comparison to standard techniques and mixtures was made. Recommendations for optimal time of restoration activities and top soil conservation are given for practical purposes. It was the aim of this project to create a new state of the art in ecological restoration of damaged areas at high altitudes of the Alps.

In order to get a basis for the practical use of indigenous seed mixtures, the demands of 14 indigenous grasses, leguminosae and herbs for a successful seed production were assessed for conventional and organic production systems. Different trials were carried out in order to optimise cultivation, weed control, fertilisation, harvesting methods and seed quality of the following species: *Avenella flexuosa, Deschampsia cespitosa, Festuca pseudodura, Festuca supina, Phleum alpinum, Phleum hirsutum, Poa violacea, Trifolium nivale, Anthyllis vulneraria, Anthyllis alpestris, Leontodon hispidus*, *Sesleria albicans, Trifolium alpinum, Trifolium badium*.

A commercial seed production of most species was established during the project period.

1. Introduction

Erosion is a basic problem found in the entire mountainous regions around the globe. Within the whole alpine area of Europe, thousands of hectares are affected every year, e.g. by construction of ski runs, ski lifts, touristical infrastructure and roads. Besides, natural erosion causes increasingly more problems. According to estimates, 5.000 hectares have to be restored yearly following interventions in high altitudes, more than 50.000 hectares of insufficiently restored areas would need imperative improvement (Krautzer, 1998).

High altitudes are the most sensible part of the Alps and can be defined as areas within the in the subalpine and alpine vegetation belt, i.e. areas above 1.600 m in the Eastern Alps and areas above 1.800 m in the Central Alps (Krautzer *et al*. 2000). Every disturbance in such alpine ecosystems leads to disturbances that require specific technical and ecological approaches.

Since the beginning of the 20^{th} century, experts worked on optimisation of restoration techniques following interventions in high altitudes (Weinzierl 1902). During the first decades of the past century, determined by limited technical possibilities, restoration activities concentrated on small space, using indigenous plant material from the surrounding area (Gams 1940). During the last four decades, the development of the Alps, especially for winter tourism, caused increasingly multiple problems. Thousands of hectares were graded for ski runs, ski lifts, streets and necessary protections from torrents and avalanches. The large-scale interventions during the sixties and seventies took usually place without basic knowledge about ecological coherence. Especially above the timberline, a lot of failures happened, producing a host of devastated areas. During this period, scientists started working on studies in order to describe the negative effects of such interventions on sub-alpine and alpine ecosystems, especially on water balance, micro-climate and soil (Cernuska 1977, Meisterhans 1982, Volz 1986). During the last 15 years, several authors described the multiple interactions between skiing and vegetation (Köck & Schnitzer 1980, Pröbstl 1990), artificial snowing and vegetation (Lichtenegger 1992) as well as ski slopes and autochthonous vegetation (Spatz et al. 1987, Klug-Pümpel 1992).

Hand in hand with the improved knowledge of the complex connections in alpine ecosystems, an increasing awareness of the necessity of a lasting restoration after interventions arised. Since the end of the sixties, a string of publications described the basic principles of restoration of ski slopes (Schiechtl 1969, Girardi 1972, Karl 1974). It was noticed early, that restoration in high altitudes was unsuccessful, using state of the art methods (Klötzli & Schiechtl 1979, Hünerwadel et al. 1982). In a first attempt, special compositions of seed mixtures were tried, using lowland species and varieties, that seemed to be adapted to the climatic conditions at high altitudes (Molzahn 1978, Florineth 1982). However, those improvements were not sufficient to achieve the goal of a sustainable restoration. The necessary use of indigenous plant or seed material was discussed more and more (Schönthaler 1984, Urbanska 1986, Greif 1985). It would be a simple but effective solution to take autochthonous plant material from the surrounding areas but under practical conditions just a fraction of the material needed is available. Research activities proving the vegetative growth of selected alpine species (May et al. 1982, Urbanska 1985, Grabherr 1987, Tschurr 1992) caused manifold trials testing indigenous plant material for restoration (Grabherr & Hohengartner 1989, Urbanska 1989, Hasler 1992, Florineth 1992). Even though this technique of transplanting showed satisfying results, the expenditure for plant production, transport and planting is excessive and application therefore restricted to small areas or to a combination with seeds. For lack of plant material in most cases, seed mixtures containing grasses and clover are normally used to re-establish a vegetation cover. But as the cheapest and most simple solution, it is state of the art in most concerned countries to use seeds of grasses and herbs, bred for the demands of grassland production in lowland regions. Most of those species are not adapted to the harsh climatic conditions of alpine ecosystems. The resulting ecological and economical damage is considerable: extreme surface runoff, soil erosion, degradation of the vegetation, need for frequent reseeding and constant fertilising, flora falsification, expensive maintenance (Greif 1985, Bittermann 1993). Due to this situation, especially the economically important winter and summer tourism got a very negative image. An obvious solution for those problems would be the use of seed mixtures containing pre-alpine and alpine species. Such indigenous grasses, leguminosae and herbs would be adapted to the alpine climate, extreme soil conditions and stress caused by skiing and grazing management. There have been successful research activities for selection of indigenous species during the nineties (Bozzo & Parente 1992, Holaus 1994, Krautzer 1995). In addition, first comparisons between alpine species and lowland species (Holaus 1998) and also between indigenous seed mixtures and lowland mixtures (Florineth 1995, Wittmann & Rücker 1995, Krautzer 1996) showed impressive results which can be expected to have most favourable effects on the environment.

A precondition for the practical use of indigenous species for restoration at high altitudes would be a successful seed production. In some alpine countries, research activities about the seed production of indigenous pre-alpine and alpine species started in the middle of the ninetieth (Krautzer 1995, Holaus & Partl 1996). In Germany and Austria, there were first successful attempts in large scale propagation of two alpine species *(Poa alpina* L., *Festuca nigrescens* Asch.), sporadically used in seed mixtures (Odermatt 1995, Holaus 1998). However, to achieve the goal of an indigenous seed mixture adapted to the specific climatic and soil conditions of a site, a minimum of four to eight corresponding suitable species would be needed.

The most risky period in which erosion processes can cause considerable damage are the weeks after sowing. Therefore, a further problem in restoration is represented by the use of cheap but inadequate methods of application, which usually lead to subsequent manifold problems (Schöntaler 1984, Lichtenegger 1994). Depending on altitude, the vegetation needs 8 to 12 weeks to achieve a vegetation cover that is able to reduce erosion to an acceptable degree (Stocking & Elwell 1976, Mosimann 1984). During this critical period, the revegetation technique has a substantial influence on erosion processes. During the last years, essential work has been done to create simulations and predicting models for soil erosion by water (Morgan et al. 1991, Renard et al. 1997, Klik et al. 1998). Important investigations have been carried out in order to get knowledge about the influence of different soils and vegetation on erosion and surface runoff at high altitudes (Czell 1972, Schaffhauser 1982, Bunza 1989, Markart & Kohl 1995). But up to now only little data is available, describing the relationship between precipitation, surface runoff and soil erosion during the period after restoration of alpine locations, which is strongly influenced by the chosen application technique (Florineth 2000). During the last years, a lot of innovative restoration concepts and application methods have been developed, but most of them are not in practical use. Restoration companies will always try to fulfill minimum requirements with a minimum of costs, assuring that cheap application methods like normal hand sowing combined with cover crops or plain hydroseeding can be used in most cases (Neuschmid 1996). We still lack on data clearly stating the effects of restoration with different application techniques and seed material on erosion processes on slopes in high altitudes.

In 1997, research Institutes from Austria, Germany, Italy and Switzerland, all close to the problems described, came together in order to built an international co-operation to answer the main questions mentioned above. As a result, the EC-funded research project ”Seed propagation of alpine species and their use for restoration of eroded areas in the Alps” (FAIR CT98-4024), short title ”Alperos”, was carried out from 1999 to 2002. The project consisted of two main aims. First, to acquire and develop a technically and economically meaningful seed propagation of already selected pre-alpine and alpine species as a precondition of a practical use of indigenous seed mixtures in the entire alpine area.
Second, to optimise application techniques and seed mixtures in order to establish sustainable vegetation adapted to the site conditions. With the help of similar trials on 8 different locations in the Alps, extensive research work was carried out to develop and assess an optimal combination of indigenous seed-mixtures and improved application techniques, compared to the current state of the art. In addition, a series of trials to get basic data about erosion processes the weeks after restoration as well as about ecological characteristics were carried out. It was the aim of these assessments to obtain a considerable improvement in lasting protection from erosion in the entire alpine region, creating multiple positive economical and ecological effects.

2. Material and Methods

2.1 Seed propagation

In order to develop and optimise the seed propagation of selected pre-alpine and alpine grasses, leguminosae and herbs in lowland regions, different trials on small and large scale were established in Austria, Germany and Italy. Different observations and assessments were carried out in order to get basic knowledge about field preparation, maintenance, fertilization, weed and disease control as well as harvesting methods, yield and product quality.

2.1.1 Description of species

At the beginning of project Alperos, first experiences were available with large scale propagation of two alpine grasses, *Festuca nigrescens* and *Poa alpina*. These two species were also integrated into the results in order to complete available data of all interesting species. For our project, 14 sub-alpine and alpine grasses, leguminosae and herbs were available in amounts of a few hundred grams up to some kilograms. Most of the chosen species like *Deschampsia cespitosa, Festuca pseudodura, Phleum alpinum, Phleum hirsutum, Poa violacea, Sesleria albicans, Trifolium alpinum, Trifolium badium, Trifolium nivale, Anthyllis vulneraria, Anthyllis alpestris, Leontodon hispidus,* have a more or less wide ecological amplitude and could be used all over the Alps. Some species are widespread but specialists for extreme site or soil conditions like *Avenella flexuosa* or *Festuca supina*. *Table 1* gives a general view of important characteristics of the chosen species.

2.1.2 Cultivation, weed control, fertilisation, harvesting methods

Plenty of different trials were carried out in order to get basic information about special demands of the selected species for seed production. For it is not possible to describe every single trial, some general information is given about trials carried out and, if necessary, the methods used.

The demands on sowing technique, field preparation and seeding were tested for all different species. Adaptation of existing sowing technique was made, where necessary, for species with bad seed flow (*Phleum alpinum, Avenella flexuosa, Deschampsia cespitosa, Leontodon hispidus)*.

Large and small scale trials were carried out to test different methods and herbicides for satisfying weed control. Effects of the most important specific herbicides of commercial seed production on indigenous species (e.g. effect of MCPB on alpine legumes, effect of urea derivatives on grasses) were tested. The selection of herbicides depended on the spectrum of weeds on the chosen locations. Special herbicides were tested for fescue species in order to find out, if some selective herbicides are useful for control of grass in grass. Most trials were made as practice trials (without replication) within the seed propagation fields. Three trials testing the effects of special herbicides for legumes (selective herbicides for legumes like as MCPB) were carried out in Austria. The use of fungicides commonly used in the conventional farming was tested in order to prevent fungal diseases (mainly rusts) for *Phleum alpinum, Phleum hirsutum, Deschampsia cespitosa* and *Avenella flexuosa*. Four methods of mechanical weed control were tested in Germany. Topping, hoeing, brush weeding and hand-rogueing. The mechanical weed control was performed when weather and soil conditions made it possible to achieve optimal effectiveness.

Optimal harvesting conditions were assessed for all species, a comparison of swath threshing to normal threshing, using a plot thresher "Wintersteiger nursery master elite", was made. The pure seeds in kg per hectare, seed losses in dependency of harvesting method and number of harvests were analysed. Suitable harvesting techniques for some species with bad seed flow rate or scalar ripening behaviour were investigated and an optimisation of harvesting date was proved.

2.1.3 Yield and seed quality

In general, information about yield refers to dried, cleaned seeds in kg per hectare, meeting minimum demands on purity. The seeds were harvested, generally dried at about 30°C for 24 to 36 hrs, then cleaned and stored at 4-6°C. The purity analyses were performed according to ISTA (1996). The seeds were examined with the aid of reflected light. The seed weight assessment was performed according to ISTA (1996). Eight replicates of 100 seeds were weighed. The germination test was performed on the pure seed fraction. Up to four replicates of 100 seeds each were placed on top of filter paper in petri-dishes (10 cm of diameter) or on a "Jacobsen" apparatus, using different temperatures (Krautzer 1988). Seeds were considered germinated when the radicle became visible. Seedlings were also examined according to ISTA (1996).

2.2 High altitude restoration

2.2.1 Description of sites

It was our intention to establish trials in the whole central and eastern alpine area. This should allow to establish a gradient of altitudes and a representative selection of different soil conditions. *Figure 1* shows the positions of the 8 locations where Alperos trials were set up. Because of technical problems, the two Swiss trials were set up one year later. Therefore, a direct comparison with the other trials was not possible. Data from the Swiss locations were therefore examined separately and were not included in the present report. After the end of the first investigation period, a landslide destroyed our site at Val Zoldana. Therefore, data from this location were only partially included. In order to guarantee representative conditions, all trials were set up directly on ski slopes, being therefore subjected to stress caused by skiing and partly by artificial snowing. The set up of the experimental sites took place between June and July 1999, assessments were carried out until October 2002.

Site factors, relevés, botanical assessments and soil parameters

Relevés and survey of site factors (altitude, gradient, exposition, etc.) are shown in *Table 2*. The relevés of the surrounding vegetation were carried out according to the Braun-Blanquet method with the following adjustments: cover of the occurring species was expressed as percentage of the total cover; mosses and lichens were not determined, but their global cover was assessed. The floristic composition was assessed, if possible, more than once during the growing season, to get a complete list of the occurring species. The cover was instead assessed only once, when the vegetation had reached its maximum development. Relevés were positioned in the surroundings of the experimental trial on natural or semi-natural plant communities as well as on previously restored areas. The species were determined and named according to Pignatti (1997), except for species not included in the Italian Flora; they were named according to Adler, Oswald and Fischer (1994). Species of the genus *Festuca* were determined by examination of cross-sections of the leaves at the microscope, as described by Pignatti (1997). The nomenclature of the plant communities follows that of Oberdorfer (1990) for the German site, and that of Grabherr and Mucina (1993) and Markgraf-Danneberg (1968) for the Austrian and Italian sites.

For each vegetation type in the surrounding vegetation and for each block of the experimental trial soil samples were collected and analysed. The soil texture of the surrounding areas and sites was estimated by an usual field method (Mc Rae, 1991). The soil colour was determined with the ”MUNSELL soil colour charts” (N = soil colour of fresh soil samples under natural structural conditions, NF = soil colour of samples under natural structural conditions, moistened until a steady colour had been achieved, M = soil colour of pasted samples moistened up to the liquid limit).

The soil analysis of air dried soil samples were carried out according to the ÖNORM Analyses of pH were performed in $CaCl_2$; electrical conductivity with a conductometer; C_{tot} and N_{tot} with an elementary analyser; $CaCO_3$ according to SCHEIBLER NH_4- and NO_3-N with an auto-analyser; P_2O_5 and K_2O with DL/CAL method.

Climatic conditions

At each site, a meteorological station was installed. The following meteorological parameters were measured:

Parameter	Unit of measure
1. Rainfall	mm
2. Wind speed	ms^{-1}
3. Air temperature 2 m above the ground surface	°C
4. Air temperature 5 cm above the ground surface	°C
5. Soil temperature 2 cm below the ground surface	°C
6. Soil temperature 15 cm below the ground surface	°C

All parameters were measured every 10 seconds, and an hourly average was registered and stored in the data logger. The weather stations were inspected monthly and the sensors were checked for accuracy. Besides, the data stored on the data logger were frequently downloaded by use of a lap top, to prevent accidental losses of data in case of damages to the data logger. *Table 3* shows the average climatic site conditions expressed as precipitation, air and soil temperatures of the different locations during the vegetation period (1st June to 31st August).
The date of flowering for the species *Poa alpina* and *Festuca nigrescens* was expressed as the date where 25 % of the fertile plants had flowered.
Beginning and end of vegetation period was individuated by the period with average daily mean temperatures above 5°C. The frost period was expressed as the period between the beginning and the end of frozen soil at a depth of 2 cm below surface.
In order to describe the changes of climatic conditions depending on altitudes, linear regressions on data of climatic stations were made.

2.2.3 Design of trials, Application techniques and Seed mixtures

Design
At each location, a similar design was used for the trials. This should enable direct comparisons and a statistic evaluation between trials. *Figure 2* shows a sketch of the trial design. Divided into 3 blocks, 3 application techniques combined with 3 different seed mixtures were compared, each combination of technique and mixture three times replicated. Because of logistical problems, we choose the split plot design (Petersen 1985), a two factorial trial with large and small plots. The application technique was designed in large blocks, within seed mixtures were established in three small plots.

Application techniques and seed mixtures

The commonly used application technique of hydroseeding (application technique A) was used on each site, representing the state of the art. To evaluate alternative possibilities, two improved or adapted application techniques (one equal for each site, the other one especially adapted for each location) were used, representing the latest technical and scientific trends. *Table 4* shows the receipts of the different techniques used for all sites:
Technique A: common hydroseeding
Technique B: the common adapted technique (hydroseeding plus mycorrhiza)
Technique C: adapted to the special demands of each site (techniques CB, CH, CP, CS, CV, CZ).
In general, the sites were fertilised only at the time of application.
In the following, some explanations are given for better understanding of the components of the techniques used (information about the products was obtained from the producers):
VAMF (Vesicular-arbuscular mycorrhiza inoculum): Spores and hyphae of *Glomus etunicatum, Glomus intraradices* and *Glomus fasciculatum*, carried on expanded clay.
"Provide verde": Bacterial and algal inoculum, nutrient conveyor; mixture of micro-organisms (mainly *Penicillium sp.*) as well as dried blue and green algae. *Penicillium* colonises the roots of the seedlings and helps to dissolve P from the soil which becomes available for plant uptake. The algae help the seeds to stick well on the ground. This is a special trade mark but the product is similar to several products used by different restoration companies.

OSFA: Organic glutener, starch- and polysaccharides concentrate; binding of seed to the soil and fastening of the soil itself (protection against erosion)
Curasol: Synthetic glutener, Polyvinyl acetate; binding of seed to the soil and fastening of the soil itself (protection against erosion)
”Biokit FL”: trade mark, concentrated nutrient-carrier made of organic substances and a polysaccharide. It contains micro and macroelements, supports micro-organisms and a fast establishment of the seedlings.
”Sanoplant”: carrier substance, a concentrated mineral powder that is able to store water and nutrients many times over its own weight. It is used in combination with a carrier-substrate that can be gravel, filled out clay, sand, wood shavings, compost etc. The use of this material should offer excellent protection against erosion, storing water and nutrients.
Geo-mats: mats like ”Curlex” are mats with a three-dimensional structure.
”Nitroform”, ”Recuform”: 38% N, synthetic –organic fertilisers containing ammonio-thio-sulphate or methylen-urea with the advantage of slowly soluble Nitrogen, (slow release N fertilisation).

All techniques were combined with three different seed mixtures in order to evaluate and quantify the ecological and economical differences of indigenous seed mixtures in comparison to the currently used mixtures of lowland species. *Table 5* gives an overall view of composition of seed mixtures, expressed as percentage of weight for each single species.
Seed mixture 1: commercial mixture, used on every site as standard mixture. The most common commercial mixture for high altitude restoration in Austria (”Schwarzenberger B3”) was chosen.
Seed mixture 2: indigenous mixture for further utilisation (cutting, grazing), containing species that are mainly indigenous or adapted to the site conditions of every location.
Seed mixture 3: indigenous mixture for areas without further utilisation, containing species that do not need or stand frequent cutting or grazing, containing species that are mainly indigenous or adapted to the site conditions of every location.

2.2.4 Methodology of assessments

Seed bank
One day before the trial-set up, one soil core was collected per each plot or block. The samples were separated in two fractions: roots, stems and leaves eventually present were discharged to avoid vegetative multiplication, the remaining soil was thoroughly mixed, and 1l of it was spread on a 20 x 30 cm tray, whose bottom was punctured to prevent water stagnation. The samples were transferred to the greenhouse and kept wet. The samples were periodically inspected and the germinated plants were recorded.

Vegetation Cover
The vegetation cover was assessed in the first year (1999) at the end of the growing season and in the following years at the flowering time of *Festuca nigrescens*. In a first step, grasses, leguminosae and herbs were separated into groups with an estimated share of total vegetation cover. In a next step, the percentage of all recorded single species was estimated. Soil, litter, stones, rocks or residuals like straw, hay, organic matter from nets or mats (in plots with covered top soil) were also assessed. As percentage values violate the assumptions of the variance analysis, the non-parametric tests of Kruskal-Wallis (for several independent samples) and the U-test of Mann-Whitney (for two

independent samples) were used instead. The tests were performed assuming that no interaction between the factors occurred.

Frequency

At the time of the flowering of *Festuca nigrescens,* the frequency of the species in the plots was assessed according to the methodology of Daget & Poissonet (1971). This is a method that was originally developed for an indirect assessment of the productivity of pastures in the alpine region. At regular distance intervals (each 20 cm) along the diagonals and the symmetry axis of the plots, a metal rod was driven vertically downward. A frame made out of wood, having one extensible side and a mobile stand to keep it stationary was used as support. By each positioning of the rod the species intercepted by it were recorded. Each species was recorded just once per each rod positioning, even if more parts of the same plants or more plants of the same species were touching the rod at the same time. The species nomenclature of Pignatti (1997) was followed. Altogether 50 observations were performed in each plot. Results are presented as changes of frequency through time within each seed mixture, as different species and different seed proportion were employed.

Ecological value

To compare ecological value of different seed mixtures, species of all sites were grouped referring to their ecological value.
Group 1: indigenous species; growing naturally under the specific site conditions
Group 2: adapted species; not indigenous under site conditions, but sustainable under comparable climatic and soil conditions
Group 3: not adapted species; not growing naturally under the specific site conditions
Group 4: species of disturbed areas; ”weeds”

Fertility

At different times during the growing season the plants of the species included in the seed mixtures were repeatedly examined and the relative proportion of plants which had flowered and produced ripe seed was estimated by sight. Species were considered as having produced ripe seed if their fruits or glumes contained filled seeds. Seeds of grasses must have at least attained the wax-ripe stage; a fingernail-test was used to check it.

Biomass

The dry matter production of mixtures was assessed in 2000 at the end of the growing season. In 2001 and in 2002 it was assessed also at the time of flowering of *Festuca nigrescens*. In each plot where seed mixtures 1 and 2 were sown, a frame (1 to 5 m², depending on site) was placed on the ground and the biomass therein was cut at a height of about 3 cm from the ground and immediately weighed. The margins of the plots were avoided for this assessment. One small sample of the fresh biomass was weighed in the field , dried and then weighed again to determine the dry matter. The remaining area of each plot was then cut and the resulting biomass was removed from the field trial In 2001 and in 2002, also the biomass in plots with seed mixture 3 was assessed at the end of the growing season. Dry matter data were subjected to analysis of variance using the software SPSS release 7.0 (SPSS Inc. 1995).

Nutrition value and digestibility

Mixed samples of three selected locations (Bayrischzell, Hochwurzen, Zillertal) were harvested in 2000, 2001 and 2002 (dried at 40°C) in order to analyse differences in nutrition value and digestibility between mixtures. For quality analysis a combination of Weender analysis and in vitro digestion (Tilly & Terry 1963) was made. Data were subjected to analysis of variance using the software SPSS.

2.2.5 Erosion trials, root biomass and tensile strength

Erosion trials

The erosion trials were carried out at the location Hochwurzen, a part of the famous skiing resort of Schladming, Austria (13,64° E, 47,36° N). The trial was set up directly beside the main Alperos trial. The meteorological station of the main trial of site "Hochwurzen" was used to get data about precipitation. In order to measure the effects of different techniques on erosion, a mobile erosion facility with three chambers was set up. *Figure 3* shows a sketch of the erosion facility. The surface-runoff and soil losses from three different plots (40 m² each) were collected at the bottom of the plots and passed through a tube to three deposit containers for heavy soil components. Water, containing dissolved soil components, ran to tip pans of 0,5 and 2 litres (working in dependence on the amount of water) for each plot. The tip pans were connected to a data logger. A bypass was collecting samples automatically. Together with the data of the climatic station, the relation between precipitation and surface runoff was worked out. Measuring the heavy soil components and the dissolved components in the sample container, soil losses were calculated too. For this work was very time-consuming, soil losses were measured only three times a year for each trial. Therefore, detailed information about soil losses during single raining events is not available.

In general, our available equipment restricted us to three chambers per year. Therefore, no replications and no statistical evaluation of the results were possible. To make our results more precise, we tried to repeat some techniques (with minor modifications). In order to guarantee comparable conditions, vegetation was killed in autumn using 4 l ha^{-1} of a herbicide with the active substance *Glyphosate*. In spring 2000 and 2001, the first 5 cm of top soil were removed and used for another part of the slope. Stored top soil from a depot near the trial was applied. *Table 6* gives a short overall view of the three different trials in 1999, 2000 and 2001-2002. Over all four investigation periods, each chamber was fertilised with 2.000 kg ha^{-1} of the organic fertiliser "Biosol", one of the most common organic fertiliser for restoration in high altitudes (Naschberger & Köck 1983).

In 1999, a pilot trial with three plots was set up in order to compare a seed mixture of commercial lowland species with an indigenous seed mixture of alpine species. The commercial seed mixture in chamber 1 contained 11 species of grasses and herbs, bred for the demands of grassland production. In comparison, the indigenous seed mixture contained 16 species of pre-alpine and alpine species, adapted to the harsh site conditions. All three plots were hand sown, using 15 g seeds m^{-2}. Chamber 2, sown with the indigenous seed mixture like chamber 3, was covered by the straw net "Greenfield S 100" (350 g m^{-2} straw, interweaved with a jute thread). During June, the equipment was calibrated and optimised. During July, we were faced with some technical problems. Therefore, results from this period were cancelled. The first trial was assessed from 02-08-1999 to 02-09-1999 in order to test the influence of the two different seed mixtures and, in addition, the effect of covered top soil on surface runoff and soil losses. During the investigation period of 1999, a precipitation of 350 mm was registered by our climatic station.

In 2000, the second trial was set up in order to prove the efficiency of the additional use of nursery grasses and cover crops in comparison to normal hand seed. All described techniques are often used in alpine areas, especially on small scale restoration sites. The trial was assessed from 21-06-2000 to 25-10-2000. For this comparison, 15 g m^{-2} of the indigenous seed mixture were used for all three plots. On chamber 2, *Lolium perenne* (variety "Guru") with an amount of 5 % was added as nursery grass to the mixture. 70 kg m^{-2} of summer rye (variety "Tyrolean summer-rye") was used as cover crop for chamber 3. This trial should give an answer to the usefulness of nursery grasses or cover crops to prevent erosion in restored areas with an inclination of more than 30 %. Water samples were collected three times (13-07, 21-08, 25-10). During this investigation period, the nutrient losses of P and K by surface runoff were calculated as the product of the volume of water (l m^{-2}) running off the plot and its concentration (mg l^{-1}). Soil texture and nutrient content of the eroded soil material were analysed at the end of the observation period. The humus and nutrient losses by soil erosion were calculated from the eroded soil material (particles smaller than 2 mm in diameter; g m^{-2}) and its nutrient content (%, mg kg^{-1}). During the investigation period of 2000, a precipitation of 810 mm was registered by our climatic station.
From 2000 to 2001, a third trial was set up in order to assess the efficiency of an additional protection of top soil (chamber 3) in comparison to a commonly used techniques, combining hand sowing with a cover crop oat (70 kg ha^{-1}, chamber 1) and to a plain hydroseeding (chamber 2). On chamber 3, again the straw net "Greenfield S 100" (350 g m^{-2}) was applied on the top soil. The first observation period lasted from 27-06-2001 to 11-10-2001. We decided to run this trial also for a second investigation period from 23-05-2002 to 28-08-2002 in order to measure possible differences in surface runoff and soil losses of the described application techniques during the second vegetation period after sowing. The vegetation cover of the three chambers was assessed at the end of June 2002. During the investigation period of 2001, a precipitation of 568 mm, during 2002 a precipitation of 1.066 mm was registered by our climatic station.
For a general comparison of all treatments and years, surface runoff were calculated as simple proportion using the measured precipitation, the resulting measured runoff and the theoretical precipitation amount of 500 mm. However, this comparison contains the conceptual problem that number and intensity of rain events, which are crucial in determining surface runoff and hence soil losses, change from year to year.

Root biomass

In the third observation year, two root samples per plot were taken at the end of the growing season according to the auger method of Böhm (1977). The samples were randomly taken inside the experimental plots (avoiding spots were residual of the pre-existing vegetation were charted in the first year at site Bayrischzell). A cylindrical steel auger (8 cm diameter) with a sharp edge was plunged into the soil to a depth of 5 cm and a soil volume of 250 cm^3 was extracted. The samples were frozen and stored until analysis. The soil then was then removed from the samples with the aid of a root-washing machine and the so-obtained below-ground phytomass was oven-dried at 70°C for 12 hours.

Tensile strength

For the determination of the tensile strength of the roots, the maximum load by the roots was determined by looking at the weight at the moment of the rupture. For this reason a single or few similar thick roots were fixed by a clip. The clip was bolstered with rubber.

Also fixed at the clip was a holder for a small container. The load was put in this container. At the moment of the rupture the weight of the load was measured. For each species, 3 plants and from each plant 3 roots were usually investigated (age of plants, growth conditions, sampling criteria?). The tensile strength was determined at distances of 5, 10 and 20 cm from the base as far as these lengths were achieved by the roots. Especially for the grasses, a distance of 20 cm was seldom found. For the investigation of the grasses, 1 to 11 shoot roots were used. The diameters of the shoot-roots at the base were mainly between 0,1 and 0,5 mm, whereas most of the remaining part of the shoot-roots had diameters between 0,1 and 0,2 mm. Because of this reason, especially these diameters were investigated, and an average of 0,15 mm diameter was used for calculations. As an example for legumes with pole-roots (taproot), a diameter of 1,6 to 8,7 mm at the base for *Lotus corniculatus* was measured, for *Trifolium pratense* ssp. *nivale* from 4,7 to 8,0 mm, for *Trifolium hybridum* from 4,2 to 7,5 mm and for *Trifolium repens* 1,8 mm. The diameter of *Anthyllis vulneraria* was between 0,5 and 2,3 mm.
For the investigations of the leguminosae with a good developed pole-root, always single roots were measured. Because of the creeping growth habit of *Trifolium repens*, its pole-root was less developed. Therefore only shoot-roots were measured for this species, .

2.3. Economic evaluation

2.3.1 Assessment of seed production of indigenous species

At the beginning of the project an investigation sheet was designed and distributed to those contract farmers of the project partner "Kärntner Saatbau" that multiplied indigenous species. The farmers, located in different places all over Austria, were asked about the specific machines they used (model, working width, etc.), the detailed working routines, working hours, prices and amounts of means of production (herbicides, fertiliser,...), the yield of cover crops, standard crops and indigenous species.
Although the data differed because of climatic and farm based specialities, the Alperos team, on the base of their own experience and of the investigation sheets filled out by the farmers, worked out five standard procedures for multiplying indigenous species. Additionally, a procedure relevant for growing winter wheat as a standard of comparison and one procedure relevant for growing summer barley as a cover crop for the indigenous grasses respectively as a preceding crop for the indigenous legumes and herbs was defined.
Most of the data necessary for standardising seed production of indigenous species were given by the contract farmers. Missing data came from literature investigations made in Germany, Austria, Switzerland and Italy. Country specific differences, especially regarding to machine costs, were taken into consideration. Finally, the yearly profit obtainable from multiplying 13 different indigenous species was compared to the profit gained from growing a standard crop like winter wheat.
Originally, it was intended to describe an additional standard procedure for organic seed production, but the demonstration trials made by the German partner showed very clearly that multiplying indigenous species under organic production circumstances is too risky and therefore not profitable at all.

2.3.2 Assessment of seed mixtures and application techniques

Data about set up costs for the different techniques were collected while establishing the demonstration trials for task 2 and 3 of the Alperos project. Additionally, relevant construction enterprises from Austria, Italy and Switzerland were invited to bid for a fictional restoration project. Details of the fictional project are given in the model description. Missing data were gathered from a literature survey. Information on potential or actual costs of commercial and indigenous seed mixtures were obtained from the company ”Kärntner Saatbau”. In order to allow a comparison of different techniques and seed mixtures, some features like inclination, accessibility, altitude, etc. had to be standardised. Therefore a model for calculating and comparing the costs of the different application techniques and seed mixtures was set up. Costs and benefits of an agricultural utilisation (mowing or grazing) were calculated and the maintenance and imperative improvement costs were estimated on the basis of a risk factor drawn from the experience of the Alperos project.

3. Results and discussion

In addition to the results presented, every partner made a lot of additional assessments that could not or only partly be integrated into this final report. Additional information for those results is available from the individual progress reports of each partner or from the consolidated progress reports.

3.1 Seed propagation of indigenous pre-alpine and alpine species

3.1.1 Cultivation and maintenance

Establishment

The optimal seed rate for the species assessed mainly depended on the dimension and ”Thousand Seed Weight” (TSW) of the seeds. Lacking on necessary experience, seed rates between 10 and 16 kg ha^{-1} were chosen for the first propagation trials. For most species, it was possible to reduce the seed rates during our project down to an average of 8 kg ha^{-1} for grasses and 10 - 12 kg ha^{-1} for leguminosae and herbs. *Table 7* gives an overall view on seed rate and recommended row spacing.

Effects of different cover crops were assessed in several trials, mainly in Austria. The effect to the different species (positive or negative) mainly depended on the type of cover crop. In general, winter cereals were not suitable as cover crop, with the exception of winter wheat with low plant densities in combination with the comparatively faster growing *Festuca nigrescens* and *Phleum alpinum*. Best experiences were made with summer cereals, especially durum wheat and summer barley. Practical comparisons showed best development of seeded grasses in combination with *Linum oleraceum* as cover crop. However, there is a wide range of suitable alternatives for the use of cover crops. In practice, the choice has to be done according to the stimulation of agricultural production and farm management. Blank seed would also be a successful method, taking into account that for most species the latest date of sowing is end of June, for species with very slow development, like *Sesleria varia,* May at the latest. Blank seed always requires more efforts for successful weed control.

Fertilisation

No special trials were carried out in order to get information about nutritional demands of the different species. From earlier trials it was obvious for most species that their ability to survive and establish on natural locations does not correspond to the demands for optimal growth and seed production. With the exception of *Avenella flexuosa* (pH < 6) and *Trifolium alpinum* (either microbial and fungal micro-organisms, or both of them, may play a beneficial role in the establishment and growth), all assessed species showed best results on soils with a reaction around pH 6, medium to high contents of nutrients and semi-intensive fertilization. *Table7* shows a recommendation for fertilisation of nitrogen, potassium and phosphorous, following the ”Austrian stipulations for fertilization” (BMLF 2000). It was our experience that an efficient fertilization in early autumn, followed by a second application of nitrogen in early spring, lead to the best results for all grasses. Legumes need an adequate supply with phosphorous and potassium. If sown in pure stands, 30 kg ha^{-1} nitrogen after sowing have a positive effect on a fast development of the seedlings.

Weed control

Nearby all assessed species were characterised by a very slow growing rate, especially during the first 5 months after sowing. During this time, depending on the site, several weeds with competitiveness much higher than the crop plants caused manifold problems. It is an experience from commercial seed production for grassland and turf, that for most species intensive weed control is necessary.

Organic farming has considerably increased its market share in the last decade. Most of the alpine countries are among the European countries with the highest amount of organic farms. Lampkin (1998) estimated that an overall area of more than 1,000,000 ha was cultivated in 1997 in the alpine countries (Austria, France, Germany, Italy and Switzerland) according to the EU-decrees 2092/91 and draft AGRI/02/61449. This area has further increased in the following years and in 2001 achieved a value of 2,670,664 ha (FiBL, 2002). It has therefore been considered interesting to verify the possibility for organic farmers to propagate seed of alpine plants. The main problem in the seed propagation, especially for organic farmers, is without doubt the weed control. Except of the only satisfying method of hand-roguing, the mechanical methods investigated proved to be unsuitable for the weed control. However, the high manpower costs connected to hand-roguing do not allow a commercial production. In addition, the strong occurrence of weeds caused in general a low quality of the seed harvested. Mechanical methods of weed control can only be recommended additionally for conventional seed production.

In Austria and Italy, several trials were carried out in order to get information about chemical weed control. As we know from the production of *Poa alpina* as well as from small scale trials, successful weed control is one of the most important factors for successful seed production. Alpine and pre-alpine species developed very slowly and are scarcely competitive. Especially the first growing year, the period from the harvest of the cover crop to autumn, decided about a successful harvest and satisfying yield in the harvesting year. In general, control of dicotyledons in seed propagation of grasses and control of grasses in leguminosae is not a big problem. *Table 8* lists active substance and application rate of herbicides that showed satisfying results in control of the most common dicotyledon weeds in Austria. A relatively small number of species caused most of the problems *(Amaranthus spp., Chenopodium spp., Matricaria spp., Viola arvensis, Veronica ssp.)*. Further, the most common herbicides for grasses control in clover are listed, showing good results against the main problem-weeds (e.g. *Poa annua*, *Poa trivialis, Apera spica-venti, Digitalis sanguinea*). However, it has to be clearly stated that, depending on the law of single countries, the use of single herbicides may be forbidden or restricted only to specific crops.

A special problem we dealt with was the possibility of a selective weed control of grasses in grass or dicotyledons in leguminosae. The investigations on the effect of special selective herbicides for fescues were made in practice trials. In *Festuca supina* we tested Cycloxydim (Focus ultra) and Quizalofop (Targa super). The positive results (effective against most grasses except of *Poa trivialis*) are visible in *Table 8* and can be transferred to all assessed *Festuca* species. Ethofumesat (Tramat) was tested in large scale trials of *Phleum alpinum* and *Festuca supina* to get information about a selective weed control of *Poa annua* in different grasses. It needs a lot of experience to avoid damage to the crop (in the worst case 100 %). Every soil, every species, every climate leads to different results. This kind of selective weed control is risky and needs an experienced expert. For good results, Ethofumesat should be used in autumn, at the end of September to the beginning of October. The first effects of Ethofumesat cannot be seen before snow melting in spring.

Effects of fungicides

In general, alpine grasses have a particular proneness to fungal diseases, especially different rusts, during the second growing period. In special trials, we wanted to get answers to the question if the use of fungicides could improve yield or quality. We decided to make our investigations only with *Phleum alpinum*, a very sensible species to rust diseases. In general, all active substances available for cereals like wheat or barley could be used. One effect after application of fungicides in late spring was a delayed ripeness, covering a clear date for the harvest, leading to loss of seeds and in general decreasing yield. Used after the first harvest, the application of fungicides lead to healthy leaves up to autumn which ensured close stands and effective suppression of weeds, showing very positive influence on yield of the second harvest.

3.1.2 Period of harvest, number of harvests, yield

Under normal conditions, the first harvest takes place during the second growing period. Only one species, *Trifolium nivale*, was able to produce ripe seeds during the first growing season, after blank seed in early April. But attainable yield and seed quality were poor. *Table 9* shows the period of harvests and the possible number of harvests for each species. The period of seed ripening for most species is comparable to lowland species and varieties, between the middle of June and the beginning of August. Between years and locations, ripening date can differ for two to three weeks. As an exception, seed ripeness of *Sesleria albicans* was attained starting from the end of May-beginning of June, followed by a more or less continuous flowering throughout the whole growing season. Again with the exception of *Sesleria albicans*, all grasses showed a compact ripening of plants, causing no problems to determine the optimal harvesting date. Comparable to lowland species, seed ripening of the investigated leguminosae took place from the end of July to August, with the exception of one species. *Trifolium badium*, showing a harvesting period from the end of June to the beginning of July. In addition, *Trifolium badium* was the only species, for which only one harvest was possible. Within three weeks after harvest, all plants that produced seeds wilted and died. This behaviour was also observed in natural environments and on our restoration trials (depending on altitude, the flowering stage was attained during the 2^{nd} to 4^{th} growing season). For *Anthyllis spp.*, the genetic characteristics of the ecotypes decided about the possibility of a second harvesting year. Some ecotypes showed a behaviour like *Trifolium badium*, but most of the assessed provenances had enough surviving plants for a second harvest. *Leontodon hispidus* was the only species with two possible harvests per year.

Not only production costs and product prices, but also yield is one of the most important factors for profitable seed production. In general, the potential yield of most species assessed was high, quite comparable to lowland species used for extensive to semi-intensive grassland production (e.g. *Poa pratensis, Trisetum flavescens , Festuca rubra*). Most species showed a decrease of yield from 1^{st} to 2^{nd} harvest, comparable to commercially produced lowland species (*Table 9*). For *Deschampsia cespitosa, Poa violacea* and *Phleum alpinum* an increasing yield was assessed for the second harvest. Experience with seed propagation of commercial species showed, that yield increases with experience of seed producers. Therefore, increasing average yields for all species can be expected for the future. It is also obvious that yields covered a wide range of values, reflecting different degrees of experience of the seed producers. For *Avenella flexuosa, Sesleria albicans, Trifolium badium* and *Trifolium alpinum*, the problems described are reflected in poor yields. For these species, successful seed production is not yet possible as long as substantial innovations solving their specific problems are missing. However, depending on satisfying production prices, an economically meaningful seed production of pre-alpine and alpine species is possible for about 80 % of the assessed species.

3.1.3 Seed quality, proposals for seed quality and minimum demands

Based on investigations on germination behaviour of alpine species (Bonde 1965, Amen 1966), different publications describe strategies and reproduction mechanisms of plants collected in their natural environments (Schütz 1988, Krautzer 1988, Flüeler 1992, Tschurr 1992, Gallmetzer & Florineth 1996). The maternal plant environment is reckoned to be in general partly responsible for variations of seed weight and seed germination (Werker 1997). At high altitudes, the life cycle of the plants is strongly influenced by the extreme climatic conditions. Factors as the duration of the growing season and the occurrence of extreme temperature events can be crucial for a plant to accomplish the seed ripening. Huge variations of the amount of filled seeds, of the seed viability and of the seed germination are possible at the same site from year to year depending on the severe nature of the environment (Chambers 1989). Hermesh and Acharya (1992) demonstrated that favourable temperatures at the time of the seed ripening result for *Poa alpina* in higher seed weight and seed germination. Such seed quality improvements under climatic conditions more favourable for the plant growth, were observed for a number of alpine grasses after seed propagation at lower altitudes (Krautzer 1995). After cultivation, characteristics like TSW and GC can change considerably. Seed quality therefore is partly depending on the species itself and partly on the growing conditions. Results of our trials show that seed germination is positively correlated with the seed weight. It is evident that seed propagation at lower altitudes results in an advantage if the seed is used in seed mixtures for the restoration at high altitudes. In such situations, very high seed germination rates and optimum seedling establishment is required in order to achieve protection against soil erosion. *Table 9* shows the average seed quality of all assessed species, characterised by thousand seed weight (TSW in g), purity (% of weight) and germination capacity (GC in %). In general, all assessed species achieved a seed quality comparable to commercially produced varieties of forage grasses and legumes.

A clear definition of necessary seed quality defined as minimum demands would be a precondition for commercial production and trade with indigenous seed mixtures for high altitude restoration. Because of lack of official regulations, a summary of all data from literature and trials carried out during our project Alperos was put together in order to create minimum demands for the assessed species (*Table 10*). The minimum values, considering possible differences in quality between years, are assuring consumers expectations. For lack of stipulations for testing the GC, results of our trials combined with earlier investigations (Krautzer 1995) were condensed in a proposal for seed testing rules according to the ”International Seed Testing Association” (*Table 11*).

3.2 High altitude restoration

3.2.1 Alpine climate and growing conditions

The demands of vegetation on environment are normally well balanced to the local circumstances (Larcher 1980, Ozenda 1988). Alpine ecosystems are characterised by unfavourable climatic conditions with limiting effects on growth and biomass production of plants. Such effects are increasing with altitude. Climatically timberline normally characterises the beginning of the alpine stage (Ellenberg 1996), where vegetation dynamics change rapidly. On ski slopes, Mosimann (1984) assessed changing vegetation dynamics at altitudes between 1.400 and 1.600 m. However, all these relationships are also influenced by multiple human interventions that took place during the last centuries. Changes of environmental conditions with altitude and their influence on vegetation have been repeatedly described (Turner 1970, Franz 1979, Ellenberg 1996). The main limiting effect for plant growth at high altitudes is temperature. On average, air and soil temperature show a decrease of 0,6°C and vegetation period decreases of 1 week per each altitude increase of 100 m (Reisigl & Keller 1994). Also precipitation and wind speed are increasing with altitude. Low soil temperatures reduce the activity of micro-organisms and therefore decomposition of organic matter and supply of nutrients.

Altitude and growing conditions

Our six climatic stations, representing different altitudes and climates; and our assessments of physiological stages of development of selected species enabled a specification of growing conditions. Additionally, a comparison with results available from literature was possible. *Figure 4* shows the beginning and the end of the vegetation period and the dates of flowering of *Poa alpina* and *Festuca nigrescens* depending on altitude, calculated as linear regressions. The dates with a daily mean air temperatures exceeding or falling below 5°C for the first time were considered respectively as beginning and end of the vegetation period for each site. The last day in spring with at least one hourly mean air temperature below 0°C was regarded as the end, the first in autumn as the beginning of the frost period. At 1.400, m the vegetation period lasted from the end of April to end of September, at 2.200 m from the beginning of June to the end of August. The date of flowering of *Festuca nigrescens*, used as reference date for starting our investigations and harvests, ranged from the last decade of June in the montane vegetation belt to mid August at our highest sites. Because of the fact that the investigated plants need about 3 to 4 weeks to attain seed ripeness, it is obvious that above 2000 m this species reaches the border where it is naturally spread. However, the date of flowering of *Poa alpina* were delayed of 6, that of *Festuca nigrescens* of 7,7 days per 100 m of increasing altitude. Finally, *Figure 4* shows the end of frost period in spring and the beginning of frost period in autumn. The inclination of the regression lines were very similar to those of the beginning and the end of the vegetation period respectively.

Figure 5 shows the number of frost days the number of growth days (daily means above 5°C, Harlfinger & Knees 1999) within the vegetation period and warm days with optimal temperature (daily means above 15°C). With one exception, frost events during the vegetation period started at the sites assessed above 1.500 m. Up to 2.400 m, 15 frost days were counted, with an increase of 1,7 days per 100 m of altitude. The warm days decreased from 72 days at 1.200 m to 17 days at 2.400 m. The growth days on our lowest site (Bayrischzell) were about 100 and decreased of 2,8 days per 100 m of altitude. According to the regression line, less than 70 days are available for plant growth at an altitude of 2000 m.

Finally, linear regressions of the mean soil and air temperatures during the vegetation period (from 1st June to 31st August) are shown in *Figure* 6. According to literature, air temperatures were found to decrease of 0,63°C per 100 m of altitude, while soil temperatures 15 cm below the surface decreased of 0,7°C/100 m.

Taking into consideration the different parameters assessed, some recommendations are possible. Because of the limited growing period, restoration activities in high altitudes should be carried out within the first 4 weeks after snow melt (Lichtenegger 1994). During this period, most soils have satisfying water contents, even on exposed sites. At an altitude of 2000 m, the period with satisfying growing conditions (mean daily temperatures above 10°C) is reduced to 60 days (Tappeiner 1996). In alpine environments, vegetation has therefore a growing season of two to three months to establish. Especially the generally slow growing indigenous species need 4 to 6 weeks of satisfying growing conditions to germinate and to establish (Urbanska & Schuetz 1986). The results of our investigations on climatic site conditions also indicate that, under average site conditions, large scale interventions and thus restoration with seed mixtures generally should be avoided above altitudes of 2.400 m.

3.2.2 Erosion and application technique

Our assessments of the vegetation cover in the plots showed, that under average conditions of high altitudes, a satisfying vegetation cover can be reached at the earliest during the second vegetation period. Application techniques with additional protection of top soil are therefore required to protect the soil from erosion during the first vegetation period. From an economic point of view, restoration companies will always try to fulfill minimum requirements with a minimum of costs. Therefore it is very important to give clear answers to authorities and restoration companies and stipulations for successful application techniques under average conditions. It is evident that a direct comparison between trials and years is not possible. Hence only clear differences or correlation are discussed.

Erosion trials on site Hochwurzen

In 1999 we managed the setup of the erosion facility during June. Facing some problems with the equipment, necessary adjustments were carried out during July. With our first trial in 1999 we wanted to measure the effects of commercial and indigenous seed mixtures as well as the effect of an additional protection of top soil. In order to avoid interactions with application techniques, we used normal hand sowing. During the investigation period, two heavy rain events with a precipitation of more than 15 mm h^{-1} took place. *Figure 7* shows the summarised surface runoff and soil losses depending on 362 mm precipitation. During our first inspection we noticed a blockage of the sampling tube of chamber three. Therefore, surface runoff from this plot did not describe the actual amount. However, between 6 % and 11 % of the precipitation did not infiltrate the soil of the unprotected plots. In comparison, the additional cover of top soil provided by the straw mat was able to reduce surface runoff to 1 % of the corresponding precipitation. A similar relation was observed concerning the soil losses. In the two chambers without additional topsoil protection, soil losses ranged from 640 kg ha^{-1} (commercial mixture) up to 780 kg ha^{-1} (indigenous seed mixture). The straw mat was able to reduce soil losses to 26 kg ha^{-1}, 4 % in comparison to chamber 1. With this first trial 1999, we also wanted to measure the influence of different seed mixtures on erosion. Due to the faster germination and early growth of commercial varieties, an increase of surface runoff and soil losses in the weeks after sowing was expected for indigenous seed mixtures. However, the harsh conditions at high altitudes (low soil and air temperature, short vegetation period, frequent frost) are causing environmental stress to the vegetation, reducing the competitiveness of commercial forage grasses and herbs and neutralising their higher productivity (Jones *et al.* 1989). Due to this fact, results obtained during the first weeks after restoration did not show substantial differences in soil losses between seed mixtures on erosion processes.

Cover crops and, in recent times, also nursery grasses are often used in restoration activities as additional protection against erosion. Due to positive, longstanding experiences of restoration companies, those techniques were compared to normal hand sowing. In the last week of June 2000, the second trial started. The investigation period lasted for 18 weeks with a precipitation of 810 mm. During the investigation period, three heavy raining events took place. The equipment worked without technical problems. This year we wanted to measure the effects of normal hand sowing in comparison to the very common techniques of hand sowing plus cover crop and hand sowing plus nursery grass. As typical cover crop, we used the old rye landrace ”Tyrolean summer rye”. As a nursery grass, we chose *Lolium perenne* ”Guru”, a variety with very good winter hardiness. Because of the extended investigation period, total surface runoff and soil losses of the chambers were higher in comparison to the previous year. Surface runoff of normal hand sowing was 9,6 % of precipitation(*Figure 8*). The effect of cover crop and nursery grass was visible. However, surface runoff decreased only to a percentage of 8,9 for nursery grass and 8,6 for cover crop. Soil losses of chamber 1 amounted to nearby 2,80 t ha^{-1}. Again, slightly lower values were measured in plots with hand sowing plus cover crop (2,68 t ha^{-1}) and the technique using nursery grass (2,37 t ha^{-1}). In a general view, the reduction of surface runoff and soil losses with the addition to the seed mixtures of fast-growing, but shortly living components was not substantial. The water samples and the eroded soil material (particles smaller than 2 mm in diameter; g m^{-2}) were analysed in order to get information about nutrient losses. Differences in nutrient value between single samples were very high. Therefore, no exact interpretation of results was possible. In general, nutrient losses were below 0,5 kg ha^{-1} for P and ranged from 1 to 1,5 kg ha^{-1} for K, being in accordance with the poor nutrient content of the soil (*Table 2*). A comparison of the amounts of losses of N, P, K and Mg between the single trials approximately reflected their different stability against erosion. Again, we noticed that the admixture of fast-growing components did not show positive influences on surface runoff and soil erosion. Compared to the unprotected normal hand seeding, the reduction was poor. Once again, the environmental stress compensated the capability of fast early growth, reducing the positive effects towards zero. The results clearly showed that the use of cover crops and nursery grasses does not have positive influence in view of a reduction of surface runoff and soil losses during the first weeks after restoration.

The third trial was set up at the end of June. It was decided to run the erosion facility up to the end of vegetation period 2002 in order to get information about erosion processes also in the year after restoration. The first period lasted for 15 weeks with a precipitation of 568 mm and one heavy rain event. The equipment worked without technical problems. With this final trial we compared the hand sowing plus cover crop technique (this year oat, also a very common cover crop for restoration) to the world-wide most used hydroseeding technique. Hydroseeding is considered one of the best application techniques to be used for steep slopes in order to prevent erosion. As a third technique, we chose hydroseeding with an additional cover of top soil with a straw mats, in order to measure the influence of protection by organic material for a second time. Surface runoff from chamber 1 (hand sowing) was 6,5 % of the precipitation (*Figure 9*). For the application technique hydroseeding, 5,5 % was measured. Again, the additional protection of top soil led to a clear reduction of surface runoff, in this case below 0,5 %.

The results obtained showed soil losses of more than 4 t ha^{-1} for chambers 1 and 2. In comparison, only 12 kg ha^{-1} soil were washed out below the straw net. *Figure 10* shows the connection between precipitation and surface runoff depending on application technique during a precipitation event that took place on 10th August 2001, described as hourly cumulative sum. From 9:00 to 24:00, a precipitation of 47 mm was measured. The cumulated surface runoff for chamber 1 was 15,8 % of precipitation, for chamber 2 12,3 % and for chamber 3 only 1,8 %. This example shows that during periods with heavy rain events the proportion of surface runoff and in turn soil losses increase very fast, while little or no surface runoff is caused by average precipitation intensities . *Figure 11* shows the same correlation between precipitation and surface runoff depending on application technique described as hourly values. It can be observed, that there is a delay between precipitation and surface runoff from half an hour to two hours, depending on intensity of the precipitation and on the infiltration rate of water into the soil. However, the comparison of hydroseeding to hand sowing plus cover crop showed comparable results. The hydroseeding was carried out by a skilled restoration company. Therefore, conditions close to practice can be assumed. One hour after application, we were faced with a raining event of two hours with a precipitation of app. 15 mm. This could have caused some wash out of not yet stabilised gluten, reducing its effect of building a protective layer on top soil. Even if we take this possible problem into account, the results at least indicate that there is a big risk in using this application technique without additional protection of top soil. In order to consolidate the results from our trial 2001, we will repeat a comparison of hydroseeding to straw cover and hand sowing in 2003.

We extended the trial for one more vegetation period in order to get information about erosion processes the year after restoration. The second period of this trial lasted for 13 weeks with a precipitation of 1.066 mm, obtained in a wet summer with 14 heavy raining events. In June 2002, a vegetation cover of 70 % on chamber 1, 75 % on chamber 2 and 80 % on chamber 3 (plus 16 % additional cover from the residual material of the straw mat) was observed. The results show a clear reduction of surface runoff in comparison to 2001 (*Figure 12*). Again, under the techniques hand sowing and hydroseeding the highest water flow was measured, representing respectively only 0,5 % and 0,4 % of total precipitation. The soil losses for both techniques reached values between 29 and 44 kg ha^{-1}, a negligible amount. However, again the technique with straw mat performed much better in comparison to the others, with surface runoff of less than 0,2 % of total precipitation and soil losses of 4 kg ha^{-1}. During the second vegetation period, the differences between the application technique used are still visible, but a satisfactory vegetation cover reduces the total surface runoff and soil losses to an acceptable degree.

Especially at high altitudes, the main aim behind the choice of a certain application method has to be a reduction of surface runoff and soil erosion to an acceptable degree. Depending on soil physical properties, climate and altitude, varying characteristics of runoff, infiltration and erosion can be expected (Markart & Kohl 1995 and Markart, Kohl & Zanetti 1997). Therefore, surface runoff and soil losses are not only influenced by the total precipitation. Both the intensity of the raining event and the kinetic energy of the raindrops reaching the top soil are responsible for erosion. Therefore, a direct comparison of all assessed application techniques between years is not possible. However, *Figure 13* gives a general view of surface runoff caused by all application techniques used from 1999 to 2001, referring to 500 mm precipitation. Using cheap application techniques like hand sowing, cover crop or nursery grass as well as hydroseeding, surface runoff ranges from 28 to 58 l m^{-2}. Only the additional protection

of top soil was able to cause a clear reduction to a surface runoff from 2 - 5 l m^{-2}. A comparable proportion between Theoretical soil losses referred to 500 mm precipitation, calculated as proportions of the soil losses measured under a certain cumulated rainfall, are represented for different application techniques in *Figure 14*. The comparison of all used application techniques during our assessments shows clear results. Depending on the climatic conditions during the investigation periods, the use of cheap and simple application techniques caused soil losses between 890 and 4.230 kg ha^{-1}. The expensive additional cover with the straw mat was able to reduce soil losses to an irrelevant amount of 11 to 46 kg ha^{-1}. Only an additional cover of top soil is able to reduce surface runoff and soil losses to an acceptable degree. For our trials in 1999 and 2001 - 2002 we used straw mats. But there are a lot of different techniques available that guarantee a sufficient protection of top soil. Straw mulching, hay mulching, different mats, nets made from jute or coconut fibre, three-dimensional mats etc. With the first series of trials, we were not able to investigate differences between the materials. But a comparison can be made to results gained from field trials in South Tyrol (Waldner 1999, Graiss 2000). There, soil losses were measured in experimental plots restored with different application techniques, with and without covered top soil, depending on precipitation. A measurement of surface runoff was not possible. However, differences between the techniques with covered top soil (straw, hay, with or without bitumen emulsion to glue the organic matter) were low. The proportion between soil losses of covered plots and those with an additional cover crop (mean proportion of 1:110) is comparable to the results of our project. In order to get additional information, we will continue in 2003 our experimentation with a comparison of straw mat and organic mulch.
Application techniques combined with an adequate additional cover of topsoil should be generally recommended for restoration of slopes at high altitudes.

3.2.3 Erosion and vegetation

The aim behind all restoration activities is to establish a dense vegetation cover as fast as possible. First and foremost, vegetation protects the soil from erosion by intercepting raindrops and absorbing their kinetic energy. If rain drops reach the ground unimpeded, they are able to damage the soil aggregates. This also reduces the infiltration of water into the soil. Water which is not infiltrated in the soil is running down the slope, causing erosion. A higher surface runoff is not definitely associated with a higher soil erosion. Not only the amount of surface runoff, but also other factors (type and cover of vegetation, soil conditions) determine the extent of soil erosion (Stocking & Elwell 1976). Mosimann (1984) worked out two non-linear relationships between vegetation cover and an erosion intensity index, depending on the altitude. Up to altitudes of 1.800 - 2.000 m (1.800 m for the Eastern Alps, 2.000 m for the Western Alps), if a minimum of 70 % vegetation cover is achieved, erosion intensity is negligible. Above 1.800 - 2.000 m, erosion phenomena were observed also at a vegetation cover of about 80 %. Direct measurements of soil losses following simulation of intense precipitations indicated that for vegetation cover values of at least 70 % soil erosion became acceptable, and cover increases up to 80% resulted in further erosion decline (Bunza 1989; rev. in Tappeiner et al. 1990). Therefore, a sufficient combination of application technique and adapted seed mixture, reaching the minimum requirement of a sustainable vegetation with 70 to 80 % cover within the first two vegetation periods, should be the aim behind restoration at high altitudes.

3.2.3.1 Seed bank

The soil seed bank is considered to be a possible colonisation source for a secondary succession after disturbances occurred, such as erosion or particularly adverse climatic conditions (Stimpfl 1985). Numerous studies were performed in the past about the soil seed bank, many of them in undisturbed or agriculturally managed soils. Some of them concerned disturbed soils, mainly following fire events or artificial removal of the pre-existent vegetation (Thompson et al. 1997), and a few of them dealt with cases where the topsoil was completely removed for building a ski run (Urbanska and Fattorini 1998a and 1998b). As most seeds are usually contained in the first 5 to 10 cm soil depth (Urbanska 1992, Frey and Lösch 1998), the attempt to take advantage of the soil seed bank for speeding up re-colonisation processes of the autochthonous vegetation implies a conservation of the topsoil. Various authors suggest removing the topsoil layer, stockpiling it, and re-distributing it later in the area to be restored, in order to achieve a faster restoration of the disturbed site (Schiechtl 1980, Mosimann 1983, Chambers 1997). This is also a cheaper alternative to the distribution of substances ameliorating the soil (Cernusca 1986). In particular, a number of studies were devoted to the effect of the topsoil storage for the restoration of mine sites (rev. in Bradshaw and Chadwick 1980), investigating the effects of the modality of storage and of the duration of the stockpiling on mycorrhiza (Rives et al. 1980, Gould and Liberta 1981, Miller et al. 1985), on microbial biomass (Visser et al. 1984, Harris et al. 1989) and on the content of viable seeds (Dickie et al. 1988). A limited number of experiments were carried out until now about this topic at high altitudes in the alpine region (Stimpfl 1985, Hatt 1991, Diemer and Prock 1993, Prock et al. 1998, Urbanska and Fattorini 1998a) or in North America (Chambers 1993, Ingersoll and Wilson 1993). Where the topsoil had been completely removed and discarded, extremely low seed densities (around 50 seeds/m²) were assessed in 10-years-old un-restored ski runs (Urbanska and Fattorini 1998b).

From soil samples of locations Bayrischzell, Hochwurzen, Zillertal and St. Anton, an assessment of the seed bank was made. All sites were machine graded. Sudelfeld was the only site where the original topsoil remained in place, even if severely disturbed. At Hochwurzen, top soil was completely removed but substituted by 3 cm of topsoil from an unknown low-altitude-location in the Ennstal valley. At Zillertal, the site was machine-graded one day before the setup of the trial. At St. Anton, top soil was removed without substitution. These differences were clearly reflected by the results obtained. In the soil samples of "St. Anton" no viable seeds were detectable, except for two seedlings of *Poa annua*. At site Zillertal, we did not find any seedlings in the soil samples. At the site Hochwurzen, the seed bank had a low density and contained mainly nitrophilous field weeds, meadow weeds and ruderal plants, such as *Chenopodium album*, *Capsella bursa-pastoris*, *Plantago major ssp. Major*, *Cerastium holosteoides*, *Persicaria lapathifolia ssp. Lapathifolia*, *Poa annua*, *Poa trivialis*, *Ranunculus acris ssp. Acris*, *Rumex acetosa* etc.

In comparison, at our site Bayrischzell, the following plant species germinated (plant order in descending individual number per unit area; species with mean density below 30 seeds m^{-2} are not mentioned here): *Mentha longifolia*, *Leucanthemum vulgare*, *Hypericum maculatum*, *Alchemilla vulgaris*, *Plantago media*, *Juncus articulatus*, *Cerastium holosteoides*, *Deschampsia caespitosa*, *Poa pratensis*, *Poa trivialis*, *Potentilla erecta*, *Festuca pratensis*, *Campanula scheuchzeri*A mean seed density of about 1.900 seeds m^{-2} was observed. The results of the site Bayrischzell clearly showed the potential importance of a dense seed bank. Altogether 54 species were determined.

Most of them (47 species) grew in the above-ground vegetation near the trial. Forbs represented numerically 66% of the total seed bank, followed by grasses (21%) and graminoids (11%). A very small percentage of legumes was found (2%). Of the 126 species assessed in the relevés performed around the experimental field in Bayrischzell, 47 were found in the samples investigated. The share of grasses, forbs and legumes were in accordance with the results of other authors, who found generally in grassland soils more extensive seed banks of forbs than grasses (rev. in Rice 1989). Referring to the classification proposed by Thompson et al. (1997), most of the species found in the seed bank belonged to the short- and long-term persistent categories, which means species with seeds persisting in the soil more than one year. The large amount of forbs found in the seed bank of the location investigated showed that in such situations the conservation of the top soil as substrate is important for an enrichment in indigenous forbs of the plant stands deriving from restoration, as their seed is difficult to obtain on the market or it is very expensive

Our results indicate that even after a partial mixing of the top soil with mineral layers, which are devoid of a seed bank, seed densities can be considerable. The conservation of the top soil should therefore be regarded as a very important task when new ski runs are planned. Discarding the top soil during the construction of a ski slope represent a waste of valuable autochthonous plant material, which is available in place for a site-specific, low-impact restoration.

3.2.3.2 Cover

Cover and application techniques

Our erosion trials clearly indicated that an additional protection of the topsoil is necessary. The comparison of different application techniques at the Alperos sites should give an answer about the influence of technique on vegetation cover, observed over four vegetation periods.

In the first phase of the establishment of vegetation, application techniques showed an important influence. The use of chemical fertilizers resulted generally in higher vegetation cover in the first year, but later on the gap was quickly filled by the other techniques. Starting from the third growing season, application technique-conditioned differences were no longer significant. From this time point the seed mixtures showed instead a significant effect. *Figure 15* shows the development of vegetation cover depending on application techniques of all sites. In autumn 1999, the first assessment of vegetation cover showed that nearby no application technique was able to meet the minimum requirement of 70 %. In the second year, these minimum requirements were met at Bayrischzell, partly at Hochwurzen and St. Anton. Within the next two periods, on all sites except Zillertal, the minimum demand of 70 % was achieved. Following the considerations of Mosimann (1984) that a minimum cover of 80 % should be achieved at altitudes above 1.800m – 2.000 m, only the hydroseeding and covered top soil techniques were able to cross this border. A statistical analysis between years and sites showed significantly better cover for techniques 1 and 3 in 1999 and 2000. Up from the third growing season, significance was detected for only two sites, while in 2002 the sole site Hochwurzen showed differences due to the application technique (see *Table 12*). For seed mixtures, significance was detected up from the second year and lasted also for 2002 on sites Bayrischzell and Hochwurzen. The results clearly showed that the use of technique 2, hydroseeding + mycorrhiza inoculum needs at least two growing season to achieve a satisfactory cover. Taking into account the results of our erosion trials, the use of mycorrhiza combined with an extremely low level of organic fertilization would be an

alternative to the commonly used chemical or organic fertilizers, provided that it is combined with an additional cover of top soil like at the experimental sites Zillertal and Bayrischzell. As at this locations the straw cover was the only difference between the two treatments where mycorrhiza were employed, the higher vegetation cover achieved in the plots with additional straw cover provides evidence for the short-term beneficial effect on seedling establishment. The straw cover is thought to improve the microclimate near the ground, preventing water stress and decreasing diurnal temperature excursions (Schiechtl 1973). Later on, such effects were no longer observed , also because the straw cover decreased very quickly already in the first two years. Unfortunately, no conclusion can be drawn about the efficacy of the mycorrhiza inoculum on the basis of the present experiments at the sites where a topsoil was present, because spores of mycorrhizal fungi, together with mycelia and infected roots, were most probably already present in the substrate and there is evidence that the infection can effectively spread through mycelial or root contact (Read et al. 1976). In order to clear this question, an additional trial will be carried out at the location Hochwurzen in 2003. A comparison of plots with mycorrhiza with plots with normal application technique will be carried out in order to quantify the mycorrhiza biomass, analysing the compounds of phospho lipid and neutral lipid fatty acids (PLFA and NLFA), according to the method of Frostegard et al. (1991).
At location Zillertal with extreme soil conditions, no technique was able to achieve the minimum cover within four growing seasons. In such case, a substantial cover increase may be only achieved with additional measures like fertilization and reseeding. The absence of significant differences between the cover scores of the plots with the mycorrhiza-hydroseeding and those resulting from the use of the plain hydroseeding is noticeable. However, we can give no clear answer to the question if it is caused by the effect of mycorrhiza or caused by the better growth conditions below the straw cover.
A comparison of residual cover of straw, hay or mats showed in tendency a better decomposition if indigenous seed mixtures were used (*Table 13*). After three years, those differences were no longer visible. In general, the results of application techniques with additional cover of top soil are comparable to those of mixture 1 with the important difference of better protection against surface runoff and soil erosion during the first two vegetation periods. The results also indicate that single components like special nutrient conveyors etc. don't have a discernible influence on restoration success under average site conditions.

Cover, seed mixtures and botanical composition

It is the main function of seed mixtures to build a dense, persistent and sustainable plant community with sufficient vegetation cover above 70 or 80 %, depending on altitude. At the end of the first growing season, there were no significant differences were found between the seed mixtures 1 (commercial), 2 (indigenous utilised) and 3 (indigenous not utilized), with the exception of Piancavallo, where the commercial seed mixture gave initially higher cover scores. Significantly better performances of the indigenous seed mixtures were first observed in the second growing season (sites Hochwurzen and Val Zoldana), and from the third growing season they became a common feature of most trial, with exception of Piancavallo and St. Anton. (*Table 12*). Looking at *Figure 16*, a steady and strong increase of cover is visible for location St. Anton whereas the normal behaviour at the other sites is a stagnation, partly a small decrease in vegetative cover. This indicates that, in contrast to the information of the ski company, the trial was - maybe accidentally - fertilized in autumn 2001 or spring 2002. Because of the unusual site conditions of Piancavallo (blocked limestone debris, relatively low altitude), no

differences in cover are visible between the three different mixtures. At site Zillertal, mixtures 2 and 3 showed significant better cover, but a cover degree below 60 %, indicating that further fertilization and seeding would be necessary to fulfill minimum demands. An overall assessment across locations, using variance analysis, showed significant better cover of indigenous seed mixtures up from the third growing season. The results obtained give a clear answer to the necessity of using indigenous seed mixtures. Except for site Zillertal, they were able to achieve 80 % cover with a single fertilization. For practical use, these results should establish a new state of the art in restoration, leading to a clear long-term reduction of maintenance expenditures. The widespread argument that fast growing components of commercial seed mixtures and, on principle, steady fertilization are needed to enable a fast protection against erosion, cannot be confirmed by the results obtained (see also chapter 3.1.2).
Dividing the combinations of application techniques and seed mixtures into their share of grasses, herbs and leguminosae, some interesting interactions between sites and mixtures could be observed. *Table 14* shows the share of groups depending on mixtures 1, 2 and their different application techniques, for the selected sites of Bayrischzell, Hochwurzen and Zillertal in % of total cover. In general, plots with indigenous seed mixtures contained a higher share of grasses and legumes regardless of the application technique. Differences between sites and between mixtures are given also by differences in the composition of the seed mixtures, which have great influence on the composition of the plant stands in the first time period after sowing. Indigenous mixtures contained higher proportions of forbs (3 % to 6 %, 4,45 % on average, while the commercial contained only 0,7 % of *Achillea millefolium*). The share of legumes was slightly higher on average for the indigenous seed mixtures (13% to 25%, 18,75% on average), but still comparable to that of the commercial seed mixture (15%). A higher proportion of forbs can be considered as a feature of the indigenous seed mixtures, as lowland commercial varieties are almost exclusively grasses or legumes. Site Bayrischzell with its high share of autochthonous vegetation contained a much higher share of herbs and the lowest share of leguminosae. A comparison of share of grasses, leguminosae and herbs of application techniques A and B, using variance analyses, showed a significant positive influence of application technique A on share of legumes and herbs (Krautzer et al. 2001).
An exact break down of vegetation cover to the main single species used in the different seed mixtures of all sites showed very interesting values and changes through the years (*Table 15*). For *Lolium perenne*, a strong decline was assessed on all sites. A low decrease was only assessed at site Hochwurzen, were a special variety, bred for alpine grassland production was used in mixture 2. Together with a high share of legumes in this plots, this variety could survive successfully thanks to its excellent winter hardiness. On all sites, with the exception of St. Anton, that seemed to have been fertilized more than one time, the share of *Phleum pratense, Poa pratensis, Trifolium hybridum* and *Trifolium repens* showed a decrease too. *Festuca rubra rubra, Lotus corniculatus* and *Achillea millefolium* were the only lowland species that could increase their share on values of vegetation cover during three investigation periods. The average cover of *Achillea millefolium* of more than 5 % in 2002 indicates that a reduction of the share in seed mixtures should be recommended (especially on lower sites). Especially the indigenous species *Festuca nigrescens, Poa alpina, Trifolium badium* and *Leontodon hispidus* were able to establish satisfyingly on most sites. Especially *Poa alpina* and *Trifolium badium* showed decreases in the third growing period. However, also species that exert an initial function and later decline can be very important, as well as the N input given by legumes in the first phase of the revegetation process. However, the

results clearly indicate differences between sites in the dynamics of single species. For practical use, a general composition of indigenous seed mixtures should be avoided. The more extreme the site conditions and the larger the restoration area, the more important would be a special composed seed mixture.
An additional comparison between the residual open soil, subtracting also the cover values for mosses, residual organic matter and stones (*Figure 17*) on three selected locations also indicated the higher potential risk of erosion if commercial seed mixtures are used for restoration.

Frequency

Frequency assessment is a suitable method for the precise assessment of changes in vegetation when the absolute number of contacts is used (Stampfli 1991). A general assessment of frequency of single species partly showed similar developments on different sites (*Table 16*). In all plots with the commercial seed mixture the valuable lowland-forage species (*Lolium perenne, Phleum pratense*), that were very abundant in the first two growing season, decreased rapidly. In particular, *Lolium perenne* had become quite rare in the fourth growing season. Instead of it, *Festuca rubra* gained steadily in abundance. *Trifolium repens*, well represented in the first two years, declined also rapidly. At single sites *Achillea millefolium* increased its frequency more or less linearly throughout the observation period. In plots with the indigenous seed mixture for further utilisation a frequency increase of *Festuca nigrescens* was observed. *Poa alpina* was abundant in a general comparison of sites (but decreased quite clearly on site Bayrischzell), while the frequency of *Phleum alpinum* decreased almost everywhere. *Trifolium repens* showed the same trend already seen in plots with the commercial seed mixture, *Trifolium badium* exhibited low, more or less unvaried frequencies, while the frequency of *Anthyllis vulneraria* peaked in the second year. Other species, such as *Lotus corniculatus* showed low and, if cutted, also stable values. Among the forbs, the most successful in gaining frequency was *Leontodon hispidus*. At some sites, the two indigenous seed mixtures had many species in common, although with slightly different weight percentages. Most of the common species showed similar trends to those above described. Concerning the relationship between application methods and seed mixtures, it has to be emphasised that the present results can be correctly interpreted only if account is taken of the fact that no fertilization was performed after the establishment of the trial. The effect of the seed mixtures appeared after that of the application techniques faded out, as many of the species contained in the commercial seed mixture are valuable fodder plants selected for high forage production and require an adequate nutrient input and intensive management, in order to achieve persistence in the plant stand. Plots with indigenous seed mixtures exhibited mid-term higher cover. Even if the plots were not further utilized, the cover remained satisfactory. In the contrary, the commercial seed mixtures with lowland species showed at some locations a negative trend after the second year. The results show that by using indigenous seed mixtures it was indeed possible to establish mid-term plant stands formed mainly by some of the species occurring in the surrounding semi-natural vegetation. Their shares showed an increasing tendency even in plots with the commercial seed mixture, suggesting that indigenous species were colonizing vegetation gaps left by the decreasing lowland varieties.
The results of the frequency analysis showed that the decline of some sown indigenous species is compensated by the increase of other sown (and non-sown) species, suggesting that such a decrease may be also caused by competition. This compensation

does not take place in the commercial seed mixtures despite of the equally increasing trend of the species from the surrounding vegetation At high altitudes, climate becomes more and more the crucial factor instead of nutrients availability.

3.2.4 Seed mixture and ecological value

There is a lot of ongoing discussions about how to define ecological values of plant stands. However, in our case we used a number of different characteristics describing the capability of a sustainable plant stand to bear climate, soil conditions, mechanical loads and additional stress factors like artificial snowing or grazing, reaching the minimum demands of 70 to 80 % vegetative cover.

Share of species according to their ecological value

Also inside our research group, very different efforts were done in order to describe differences, e.g. weighted scores of the ecological indicators of Landolt (1977), assessed by our German partner, or an efficiency index (Parente et al. 2002). More detailed information can be found in the individual progress reports: A method that would allow a comparison of different sites and mixtures was developed for this report. A classification of mixtures referring to the ecological value of the assessed species was made. *Figure 18* describes the criteria of groups, following the ecological value of species summarized inside. In general, only the species allocated to groups 1 and 2 can be expected to be sustainable under the specific conditions of each site. Groups 3 and 4 should not be able to survive under the specific site conditions and should disappear through the years. Therefore, mixtures with a high content of indigenous and adapted species can be expected to produce sustainable plant stands under site conditions. A high ecological value can be assigned under this point of view. *Figure 19* shows a comparison of mixtures 1 to 3, assessed as total cover of 2002 in comparison of all sites, additionally divided into groups of different ecological value. It is visible, that the share of indigenous species was above 40 % for indigenous seed mixtures and about 15 % for commercial mixture (mainly as a result of immigration from other plots). The share of adapted species was about 30 % for indigenous mixtures. The commercial mixture contained about 2 to 3 % more, mainly one species, *Festuca rubra*. Summarizing the valuable groups with expected sustainability, indigenous seed mixtures reached the minimum requirement of 70 % cover. In comparison, the share of valuable groups from the commercial mixture remained below 45 %. *Figure 20* gives an impression of the development of the share of grouped species over the years, compared to their share (in % of weight) in the seed mixtures. The continuos increase of cover of indigenous species is visible. Indigenous species were more or less able to retain their original share corresponding to their percentage in the receipt of the seed mixture. In plots sown with the commercial mixture, the share of not adapted species decreased from 50 % in the seed mixture to about 20 % in the plant stands, mainly at the expense of total cover.

For practical use, the results clearly indicate that commercial seed mixtures, containing a high percentage of species that are not adapted to site conditions, would need repeated seeding and fertilization in order to achieve and maintain a vegetation cover ensuring sufficient protection against erosion. In a long-term perspective, it can be assumed that the lack of sustainable indigenous species will cause steady efforts and thus expenditures, especially at altitudes above 1.800 m.

Fertility

The ability to attain the seed ripening is a very important characteristic of species in order to build up a soil seed bank. Investigations at an altitude of 2.400 m showed a potential seed production of alpine species up to 60 kg ha^{-1} (Krautzer 1999). Especially on machine- graded soils, the lack of seeds is obvious (see also chapter 3.1.3.1). For some species, the dissemination would have special importance. For example, *Anthyllis vulneraria* is biennial (Hegi 1964, Pardini et al. 1997, Vescovo 2000) and *Trifolium badium* is at most triennial (Hegi 1964, Urbanska 1995) and their permanence in the plant stands is therefore is bound to the sexual reproduction. However, with increasing altitude, the vegetation period decreases of about one week per 100 metres (see also chapter 3.1.1). *Figure 21* shows the results of a general assessment of the main species used in the commercial and indigenous seed mixtures. The management practices (cutting), particularly the time of the biomass harvest, were instead a limiting factor. But for almost all sites, it was possible to make the necessary assessments. Partly the edges of plots, partly surrounding areas sown with the commercial mixture, partly surrounding ski slopes were used for those assessments. In the case of the sites Bayrischzell and Piancavallo, the climatic conditions, which are not extreme, allowed all species to attain the seed ripeness. The assessment of fertility also showed that commercial lowland species, with the exception of *Agrostis capillaris,* are not able to get fertile at altitudes above 1.800 m. *Anthyllis vulneraria* did not get mature at altitudes above 2.000 m and should be substituted in seed mixtures for such altitudes by *Anthyllis alpestris*. Under average climatic conditions during the growing season, indigenous species are able to produce ripe seeds up to altitudes around 2.300 m.

Number of species

Also the species enrichment occurred under the given conditions quite quickly, as the species number was on average about 2,3 times higher than the number of the sown species, regardless of the treatment. *Table 17* shows the results of a parametric variance analyses of total number of species of all sites in 2002. On most sites, a significant higher numbers of species were found in plots where indigenous seed mixtures were used. *Figure 22* shows the average number of species depending on the seed mixtures, described as average across all sites from 1998 (composition of seed mixtures) to 2002. Up from the second year, total number of species remained more or less constant. Indigenous seed mixtures contained on average not more than 1 - 2 more species. As it was already visible (see also above line share of species according to their ecological value), the decline of sown commercial species was compensated by the increase of other sown indigenous or adapted species, immigrating from neighbour plots. In practice, on restoration sites with an average size of some thousand square-meters to some hectares, immigration from the surrounding areas would need years to decades (Klug-Pümpel 1992).

Root biomass

Table 18 shows the results of the measurement of the root biomass depending on seed mixture and application method for the sites Bayrischzell and Hochwurzen. The measurement of root biomass at the two sites did not show significant effects of the main factors. A significant interaction of seed mixture and application technique was found in the analysis of variance for both sites. The data showed quite a large variability so that the interpretation of data is quite difficult. In general, the commercial seed mixture achieved lower values than the indigenous ones at Bayrischzell, while at Hochwurzen the commercial seed mixture performed a bit better. The total root biomass decreased with altitude. The highest below-ground biomass was found at Bayrischzell in two combinations: 1st the indigenous seed mixture for further utilisation combined with the plain hydroseeding and 2nd for the indigenous seed mixture without further utilisation combined with covered top soil. The latter combination yielded the highest below-ground biomass also at Hochwurzen. In general, the output of the present experiment suggests that the use of indigenous seed mixtures results in hypogeal biomass values at least as high as those of the commercial seed mixtures. The re-establishment of an intensive rooting of disturbed sites in mountain regions is known to be a long-term process. Root dry matter about 2 to 5 times larger than in Bayrischzell on the third year (between 3 and 7 g/100cm²) were reported in 10-years-old ski runs at similar altitudes (Schauer 1981, Schauer 1988). These values were still 1/10 to 1/5 of those founds for the undisturbed surrounding vegetation (Haid 1982 rev. in Cernusca 1986).

Tensile strength

It was the aim of the investigations of the tensile strength to get fundamental knowledge about the resistance of the roots of different species as base for an evaluation of different stands against mechanical loads and erosion. For this reason, data about the tensile strength of single roots of the different species was assessed. For an evaluation, the knowledge of the rooting types of the different species, including the number, diameter and length of the roots is necessary. Only by knowledge of these fundamental facts an evaluation of the resistance against erosion of different stands is possible.

The main effort done during our investigations was directed towards the measurement of the tensile strength of single roots of different species. Especially species with high coverage in the stands were assessed. The influence of the anatomical structure, including the different patterns of ageing and their growth-types is obvious (Kutschera & Lichtenegger 1982 and 1992, Kutschera & Sobotik 1992). Most of the investigated species belonged to grasses and leguminosae. Typical for grasses is the lack of a secondary growth and the presence of thickenings of particular cell-rows of the cortex, especially the endodermis so as of the stele. The diameter of the roots of grasses depends on the size of the plants at the time of their development. The diameter of the roots of leguminosae and other species with secondary thickening depends mainly on the amount of the secondary growth. The amount of the secondary growth shows particular differences between species. For example, the secondary growth of the shoot-roots of the runner-building (creeping) species *Trifolium repens* is very low. The species of leguminosae with well developed pole-roots are developing much higher diameters.

A particularity of all leguminosae are fibres. The high tensile strength of the most leguminosae is connected to the presence of fibres. The highest tensile strength measured was 9,2 kg at a diameter of 2,5 mm for *Lotus corniculatus*. The variation of the tensile strength at almost the same diameter ranged from 3,2 up to 9,2 kg. *Trifolium nivale,* with diameters of more than 1,0 mm, showed very similar values of the tensile strength. By diameters above 1,0 mm the variation of tensile strength was very high. For grasses (diameter 0,1 to 0,2 mm) the highest tensile strength was measured for *Poa alpina* with 1,7 kg (average diameter 0,15 mm).

The tensile strength of the assessed grasses and leguminosae showed generally high variations (*Figure 23*). For *Lotus corniculatus*, the tensile strength seemed to be related very faintly to the diameter. This could be explained with the different stages of development of single plants. The low tensile strength of *Trifolium hybridum* was connected to the short life of this species. The roots began to die already during the third growing season. However, the closest relation between diameter and tensile strength was measured for *Lotus corniculatus*, followed by other Leguminosae like *Trifolium nivale* and *Anthyllis vulneraria*. *Trifolium badium* has usually a short life span up to the year of flowering (2-3 years). For this reason, no younger individuals of this clover could be found and measured. In general, leguminosae showed on average a tensile strength twice as high as grasses. Also some special forbs like *Leontodon hispidus* are able to build up a deep rooting system with excellent values for tensile strength. A further comparison of tensile strength was done between the most important species of seed mixtures 1 (commercial) and 2 (indigenous) for site Hochwurzen (*Figure 24*). According to the grouping of species referring to their ecological value (see also *Figures 18* and *19*), it is clearly visible that indigenous and adapted species, and in particular the Leguminosae, show in general better tensile strength. Using indigenous seed mixtures for restoration in high altitudes, better tensile strength and thus better resistance against mechanical damage caused by cattle, preparation of ski runs or tourists can be expected.

In general, the assessment of our EU-project Alperos about the ecological value of seed mixtures clearly showed multiple positive ecological effects up from the 2nd year after sowing, if indigenous species were used.

3.2.5 Yield and forage quality

Growing height
An assessment of the growing height of the three seed mixtures was made at each site. The results showed higher growth for commercial mixtures, but only in tendency. However, a statistical evaluation of all sites in the fourth growing season did not show significant differences (*Table 19*). Results obtained have to be discussed considering the reduced availability of nutrients. The commercial mixture consisted of a high percentage of top grasses with the potential ability to grow up to more than one meter under climatically favourable conditions and in presence of adequate nutritional input. Both factors were limiting under the site conditions. Because of the growing height is also related to biomass production, no big differences in yield were expected comparing the different seed mixtures.

Yield
In some parts of the Alps, the use of ski runs or other restored areas is of great importance for mountain grazing, especially in Austria, Switzerland and Germany. Site-adapted yields and satisfying forage quality are important goals of grassland management of pastures. In general, a sufficient amount of precipitation can be expected at higher altitudes. Temperature decreases with an average value of 0,6°C per 100 m of altitude (Ellenberg 1996). Therefore, temperature is the main limiting factor for yield at high altitudes, although under practical conditions different site factors can have a strong influence (Spatz & Voigtländer 1969). *Table 20* shows a comparison of dry biomass yield at all assessed sites. Dry matter of the indigenous mixture without further fertilization was assessed in 2002 as an additional information. In general, biomass production of non utilized areas was clearly below that of grazed or cutted areas. However, it is obvious that at most sites biomass yield increased from the first to the third harvest, showing a decrease on fourth harvest. At site Bayrischzell, the highest yield for the commercial seed mixture was assessed for the first year, for the indigenous seed mixture with further utilization for the second year. Comparing the mean yield from different sites, a decrease of yield with altitude is visible, from 2.800 kg ha^{-1} at 1230 m down to 300 kg ha^{-1} at 2.280m (site Hochwurzen). This decrease is more or less linear, but extreme site conditions like at Piancavallo can cause a strong deviation (Pötsch, Bergler & Buchgraber 1998). The results of a statistical analysis of the effects

of techniques and of the two utilized seed mixtures at all sites and years are condensed in *Table 21.* A significance of techniques could only be found for site Hochwurzen in 2000 and for site St. Anton in 2002. Therefore, it can be concluded that the techniques used in general did not influenced the yield. A comparison of mixtures showed some significant differences in 2000 and 2001 but no longer in 2003. At Bayrischzell, the commercial mixture showed better yield in the first harvest year for 2000, while at site Val Zoldana the highest yield was given by the indigenous mixture. At sites Hochwurzen and St. Anton, the indigenous seed mixture performed better in 2001. A statistical comparison between all sites did not show significant differences in dry biomass yield of commercial and indigenous seed mixtures.

Figure 25 shows a comparison of dry biomass yield, made only for the sites Bayrischzell, Hochwurzen and Zillertal, three locations with alpine pastures in the surroundings. The sites Piancavallo and St. Anton were not considered because of the special site conditions of the first and of the obvious fertilization of the latter. Compared to yields from alpine pastures located in the eastern Alps of Austria (Schechtner 1959), the yields assessed at Bayrischzell and Hochwurzen were comparable to non fertilized pastures.

Gruber et al. (1998) calculated for pastures a yield decrease of 2,44 kg dry biomass per meter of altitude. lack of single values, it was not possible to calculate a regression for our sites. However, for our restored areas, the decrease of yield with altitude seemed to be higher.

Comparisons between yield of ski runs and surrounding areas that were not graded before showed a close correlation between potential yield and humus content of the soil (Bohner & Buchgraber 2001). Our findings indicate that the potential dry biomass yield of restored sites at high altitudes is comparable to alpine pastures, assuming that available humus was stored and applicated again. The use of indigenous seed mixtures did not lead to lower yields.

Forage quality

Even for alpine pastures, forage quality is an important parameter. Indigenous alpine species have just a short time span for growing and ripening, which accelerates their development (Caputa & Schechtner 1970). This could explain a decrease of digestibility with increasing altitude. However, Gruber et al. (1998) describe a time span from the beginning of June to the mid July as the period with optimal yield and forage quality for pastures at altitudes between 1.100 m and 1.800 m. According to those results, our date of harvest at the beginning of flowering of *Festuca nigrescens* can be assumed as an optimum (see also chapter 3.1.1). For this reason, only the first cut of site Bayrischzell was used for analyses of digestibility. In comparison to indigenous species, varieties contained in the commercial mixtures need much better growing conditions and a long time span for their development. From this point of view, an earlier stage of development at the date of harvest and therefore higher forge quality was expected.

Some of the main parameters for forage quality (Weender analyses, digestibility and energy concentration) are listed in *Table 22.* Data of some important parameters like cell wall constituents or minerals are still missing and will be completely available up to summer. However, a short description of nutrition value and digestibility is possible. As expected, digestibility showed a decrease with altitude, while the contents of fibre increased. A reduced digestibility of plots were indigenous seed mixtures were used is also visible. The differences are also reflected in values of energy concentration and fibre. A variance analysis done for the main parameters of each site did not show significant differences in digestibility and energy concentration for site Zillertal, significant differences depending on year and mixtures at site Hochwurzen and significant differences depending on mixtures for site Bayrischzell. In general, better digestibility and energy concentration can be expected for commercial seed mixtures. At the location with the highest altitude, Zillertal, no significant differences were found.

3.3 Economic evaluation

3.3.1 Assessment of seed production of indigenous species

Although seed propagation for common species is known to be very profitable for experienced farmers, it is not so easy to find contract partners for multiplying indigenous species. Up to now costs and risks have been very high. As a result of the Alperos project new production guidelines should reduce the risk of low yields and give clear answers regarding costs and revenues that can be expected. The project aims at delivering necessary economic data to calculate profit for large scale multiplication of indigenous species. Additionally estimations of the EU wide benefits of transforming farmland from food production to multiplication of indigenous species and thus reducing the problem of overproduction is shown.

By far the most important aim of this chapter is the calculation of costs and returns, namely the profit of multiplying different indigenous species under different climatic conditions and geographical features from a farmers perspective. In order to decide whether to produce standard crops or to multiply indigenous species, farmers in different countries have to compare the profit of both alternatives on the basis of a full cost and benefit calculation. For this purpose, four standard cultivation procedures were worked out:

Standard procedure 1 is relevant for all *Festuca* species (*Festuca supina* and *Festuca pseudodura*)

Standard procedure 2 is relevant for all the other graminea species (*Poa violacea, Phleum alpinum, Phleum hirsutum, Deschampsia cespitosa, Avenella flexuosa* and *Sesleria albicans*)

<u>Year of establishment:</u> All species in standard procedure 1 and 2 are sown as an under-seed, with summer barley as a cover crop. Two rounds of herbicide and fertiliser applications are carried out after the harvest of the cover crop. Types of weed killer differ between standard procedure 1 and 2. In late autumn of the first year a clearing cut with a flail mower is performed.

<u>2nd year:</u> Before the first harvest of seeds, two herbicide treatments have to be performed in standard procedure 1 and an extra 3rd herbicide application in standard procedure 2. The extra weed killer application in standard procedure 2 is a labour intensive manual application of a total herbicide. Additionally a spring fertilisation with mineral fertiliser is carried out in both procedures. After the first harvest of the indigenous seeds in early summer, an insecticide and a herbicide is sprayed in two different steps and two times mineral fertilisers are spread onto the field during summer and fall. In autumn of the second year a clearing cut with a flail mower is again necessary. Supplementary, for the *Festuca* species, the surface has to be loosened by a rotary harrow to prevent lawn building.

<u>3rd year:</u> After the spring fertilisation, two rounds of herbicide treatments for standard procedure 1 and three rounds for standard procedure 2 have to be performed before the second harvest of seeds is done.

After the second harvest the species stay on the field as a greening till autumn ploughing.

Standard procedure 3 is relevant for *Trifolium alpinum* and *Trifolium nivale*
Standard procedure 4 is relevant for all the other legumes (*Trifolium badium, Anthyllis vulneraria* and *Anthyllis alpestris*)
Year of establishment: All species in standard procedure 3 and 4 are sown in an open sowing in August immediately after the harvest of the preceding crop (summer barley). Following field preparation with a plough and a heavy harrow, the spreading of mineral fertiliser and the seeding of the indigenous species, three rounds of weed control have to be performed. The year ends with an autumn fertilisation.
2nd year: After the removal of weeds with a total herbicide applied by a mechanic wiper, standard procedure 3 gets a clearing cut at the begin of May and a first harvest of seeds in August. In autumn one round of weed control and fertilisation is performed. All the other legume species (standard procedure 4) receive the individual weed control with the total herbicide and the harvest of seeds takes place without a previous clearing cut. Standard procedure 4 finishes in the second year.
3rd year: In standard procedure 3, again the special weed control with the total herbicide is undertaken in spring and the clearing cut takes place in May. Harvest is again in August.
After the last harvest the legumes stay on the field as a greening till autumn ploughing.

Standard procedure 5 is relevant for *Leontodon hispidus*
Year of establishment: Following an open sowing in July (see standard procedure 3 and 4) two rounds of fertilisation and one round of weed control as well as a late clearing cut are performed in the year of establishment.
2nd year: It starts with a special herbicide application, a round of fertilisation and a chemical pesticide treatment. There are two harvests in the second year, one at the end of June and one at the beginning of September.

Hay harvest: In most cases the amount of hay produced is so little that harvesting is not considered as profitable. Therefore the hay is chopped into small pieces by the combined harvester and distributed evenly on the field. In those few cases, where enough hay for baling is produced, the costs of harvesting and the revenue from selling the hay are considered as being equal.

Full costs are calculated by summing up all machine, labour, product and additional (e.g. drying, cleaning, insurance, etc.) costs for multiplying the different indigenous species as well as for winter wheat and summer barley. Labour costs and machine costs are according to the recommendation made by the different national machine co-operation companies (e.g. ÖKL 2001, KTBL 2000) and therefore differ between the countries. Material costs reflect usual commercial trade prices.
Revenue is composed of payments for seeds and straw (only for winter wheat and summer barley) and, if applicable, GAP direct payments. If summer barley is used as a cover crop for the graminea species, yield of barley is supposed to decline by 1/3. The average yields of seeds from indigenous species is calculated as the average yield of the last three years of all large scale respectively small scale multiplication trials within the Alperos project (for more information see chapter 3.1.2).

Comparison between winter wheat and the indigenous seed production is calculated per ha and related to one year of production. Prices are given in Euro and no VAT was calculated.

Results

Table 23 lists the total costs split into machine, labour and additional costs per year and ha. Machine costs reflect the circumstances in Austria, additional costs include material costs like costs for herbicides, fungicides, fertiliser, seeds as well as costs for insurance, cleaning, drying etc.. Indigenous seed production lasts more than one year, therefor all cost components are related to one year. That means that costs for standard procedure 1 to 3 are divided by the factor 3 and for standard procedure 4 and 5 they are divided by the factor 2.

With the exemption of *Leontodon hispidus* machine costs do not differ substantially between the indigenous species. Because of the high machine costs that occur during harvest *Leontodon hispidus*, which allows two harvests within one year, shows much higher machine costs than the other indigenous species. The extra manual weed control in standard procedure 2 is the reason for almost doubling the labour costs in contrast to all other standard procedures. Multiplication of indigenous species occupies the field for two to three years and in the year of establishment no harvest can be expected. To allow a comparison with annual crops all data have to be related to one year. Therefore total activity for multiplying indigenous species, related to one year, is less compared to annual crops and that's why machine and labour costs are more than twice as high for annual crops. *Table 23* refers to costs in Austria. Machine costs are much lower in Germany and Italy while labour and additional costs to not differ substantially between the countries in question.

The category of additional costs cover a wide range of different costs. Cleaning and drying of seeds from indigenous species has to be done with special equipment and therefor these costs are much higher than those for common crops. Likewise certified seeds for rare species are very expensive and hence the legume species and *Leontodon hispidus* have high additional costs because of high seeds costs. Costs for pesticides make up the highest proportion of the additional costs for the graminea species. Expenditures for fertiliser do not differ very much between the species. Annual crops have less additional costs because of lower costs for pesticides, seeds and drying.

Highest total costs per year have been calculated for multiplying *Leontodon hispidus*. They are as high as for winter wheat, the standard crop for comparison. Lowest total costs have been calculated for the *Festuca* species.

Table 24 shows the differences in profit per ha year^{-1} between winter wheat and indigenous seed production for Austria. The costs and revenues of summer barley grown as a preceding respectively cover crop were transformed depending on the underlying standard procedure (2 or 3 years of utilisation) and added to those calculated for the relevant indigenous species. Average difference is calculated taking into consideration the arithmetic means of the yield for indigenous seed production over the last three years of all large and small scale results shown in *Table 9* of the final report. Minimum and maximum difference show results underlying best respectively worst yield scenarios. Producer's prices for winter wheat and summer barley reflect average market prices in 2001/02. GAP direct payments are according to those paid in the year 2002. Possible producer's prices for indigenous seeds were given from the project partner Kärntner Saatbau.

Taking the average amount of yield clearly shows that multiplying indigenous species with the exemption of *Trifolium alpinum* is very profitable for farmers compared to growing winter wheat. Especially multiplying *Anthylis vulneraria, Leontodon hispidus* and *Avenella flexuosa* seems to bring the highest profit. As already discussed in Chapter 3.1.2 the variation of yield for indigenous species is very high depending on weather condition and experience of the farmer. The Minimum/Maximum column of *table 24* shows the variation taking into account the worst and the best yield over the last years. For example, *Phleum alpinum* has an average yield of 160 kg and the average advantage over winter wheat is 927,- Euro/ha/year. But in a bad year only 20 kg of seeds can be harvested and in that case growing winter wheat would have been much more profitable (- 699 Euro), while in a very good year the yield was as high as 280 kg and the corresponding additional profit was 2.263,- Euro.
Therefore farmers who want to start multiplying indigenous species should be aware that especially in the beginning the risk is quite high. Additionally market analysis reveal that prices for indigenous seeds are very sensitive to supply and demand and hence will decline rapidly as soon as production increases.
Results showed in *Table 24* are relevant for Austria. Because machine costs are lower in Germany and Italy the profit for winter wheat is higher than in Austria. Multiplying indigenous species causes less machine costs per year compared to winter wheat (see *Table 23*) and consequently the average profit difference in Germany and Italy decreases 60 to 65 Euro/ha/year for grasses and about 50 Euro for leguminosae compared to Austria. Since there are two harvests within one year for Leontodon hispidus, the machine costs are higher for this specie and hence the difference is 6 Euro higher in Germany and Italy than in Austria.
In this calculation no national payments were taken into account because they differ not only between the countries but also within one and the same country. Estimations for Austria show, that taking Austrian circumstances (ÖPUL) into consideration, the profit difference between winter wheat and multiplying indigenous species declines by 170 to 200 Euro/ha/year because national payments are much higher for growing winter wheat than for multiplying seeds.

Assessments based on the number of ski slopes that are build or rebuilt every year show that presently about 400 to 500 ha of indigenous seed production would be needed within the EU if indigenous seed mixtures are used exclusively. The demand for indigenous seeds would be substantially higher considering that all restoration activity at high altitude that follow infrastructure measurements, like road construction, etc. should use indigenous seeds. Moreover, after the enlargement of the EU, the request for indigenous seeds will increase again.
Switching 1.000 ha arable land from wheat production to production of indigenous species would save about 350.000 Euro per year of direct payments from the EU budget. In addition overproduction of cereals could be decreased by 5.000 tons a year.

From the ecological point of view the production of indigenous species depends on the use of herbicides and therefore is partly not environmentally friendly. But an over all estimation has to pay attention to the ecological value of using indigenous species for restoration measurements, described in the results (see chapter 3.1).

3.3.2 Assessment of seed mixtures and application techniques

Restoration of eroded slopes at high altitude with state of the art application techniques and standard commercial seed mixtures frequently lead to unsatisfying results with maintenance and imperative improvement costs that are often higher than the original set up costs. Because of problems with infrastructure not every slope in a high altitude can be looked after carefully, respectively agricultural utilised and therefor restoration efforts have to take into consideration if a further agricultural utilisation like grazing or mowing is desirable or not. The goal of this chapter of Alperos project was to compare different application techniques and seed mixtures from an economical point of view and on a long term basis that not only considers set up costs but additionally maintenance and imperative improvement costs.

Description of the model:
The restoration of one hectare area in an altitude of 1600 m, using 4 different application methods and 2 different seed mixtures has been simulated. The slope of the area is in maximum 70%, the shape of the field is rectangular and the distance from the last main road to the restoration side is 10,5 km. The first 10 km are paved roads and therefor transport can be done by a normal lorry, the last 500 m transportation only can be realised by a special carrier (= Muli) or by hand. Water access is in a maximum distance of 300 m from the restoration side. There are no differences in the necessary preparation (e.g. cleaning) of the side concerning the different application techniques.
Technique 1: Plain Hydroseeding (T1)
The application is done in a single operation. All the material (cellulose, gluten, mineral fertiliser and seed mixture) is mixed in a 2.000 l tank carried by the Muli and sprayed onto the area with a sprayer and pipelines.
Technique 2: Hydroseeding with Mycorrhiza (T2)
The same technique but other components (organic fertiliser, different gluten) that should specially support the development of the Mycorrhiza.
Technique 3: Hydroseeding with Mycorrhiza and covering the side with straw (T3)
The first step is the same as in Technique 2. In a second step straw is spread over the area by a blower and then the straw is fixed with bitumen which is distributed with the sprayer. Technique 4: Hydroseeding plus fixation with a Curlex mat (T4)
After hydroseeding (mixture includes rye as a cover seed) a three dimensional mat (Curlex) that fixes the material is nailed onto the area per hand.

Table 25 shows the amount of material and working hours for application techniques T1 to T4 and the price per unit in €. Prices are given by commercial enterprises and therefor differ from prices in subtask 4.1. No VAT was calculated.

Working hour per ha was a difficult parameter to measure, because figures in literature and specification from the construction enterprises differed by more than 200 %. Therefore a timing was done during the set up of the Alperos project and hours per ha for the different techniques was fixed by the Alperos team after an additional consultation of experts from construction enterprises.

Table 26 shows material, machine, labour and total costs in Euro/ha for T1 to T4. No VAT is included and the material costs are without costs for seeds which are shown separately in *Table 27*.
Material costs are lowest for plain hydroseeding (T1). The addition of a soil improvement material (e.g. mycorrhiza) and other special additives (e.g. organic carrier

and fertiliser) quardruble the material costs. Covering the restoration area with straw and fixing the straw with bitumen adds almost 1.000 Euro to the material costs (see T3 in comparison to T2). The material costs for a three dimensional mat ("Curlex" mat) amounts to nearly 39.000 Euro per ha (T4). Although nets made of straw and coconut fibre can reduce the material costs to about 22.000 Euro per ha, the use of nets for fixing the applied materials is very expansive and should only be considered where really necessary (e.g. very steep slopes with a high risk for erosion).
The highest machine costs are calculated for technique 3. This is because T3 is divided into three stages and therefor sprayer costs and blower costs are much higher than in all the other techniques. Additionally the transport of 5.000 kg straw for covering the restoration side is expansive and needs a lot of handicraft which affects labour costs (see *Table 26*). But labour costs are even higher for technique 4 where covering the side with a mat and fixing this mat with nails takes approximately 65 hours per ha.
Summing up the set up costs reveal that plain hydroseeding is by far the cheapest technique. Including mycorrhiza increases the costs by more than 3.600 Euro. Covering the restoration side with straw (or hay) costs almost 2.600 Euro per ha, while applying a net leads to a cost explosion.
But as the erosion trails (see Chapter 3.2.3 and Figure 14) have shown the use of application technique T1 and T2 lead to big surface runoff, soil losses and reduces the vegetation coverage. Therefor imperative repair actions have to be done. The costs of this repair actions can be expressed as a cost proportion for a complete new restoration activity. Estimations made from all erosion trails of the Alperos project suggests that 60 % of the sites have to be set up again if there is no protective coverage. That means that the total costs for application technique T1 and T2 must be multiplied by the factor 1,6 so that the actual costs for T1 amounts to 3.493 Euro and for T2 to 9.280 Euro. A comparison between T1 and T3 (without mycorrhiza) reveals that from an economic point of view T1 is still by far the cheapest application method.

For a successful restoration the amount of seed mixtures that include indigenous species could be reduced by 80 kg/ha compared to commercial seed mixtures. Despite of reducing the amount of seeds the costs are still 3 times higher when using indigenous seed mixtures. But the results from the Alperos project indicated that in order to reach the minimum total vegetation coverage for a successful and sustainable restoration (at least 70 % total vegetation coverage) restoration sites that use commercial seed mixture have to do maintenance actions. Therefor costs of 1.594 Euro per ha, for reseeding (dry seeding with 100 kg/ha commercial seed mixture) and two times fertilisation (2.500 kg/ha Biosol) have to be added for a sustainable restoration when using commercial seed mixtures. As a consequence the use of indigenous seed mixtures is on a long term basis cheaper than commercial seed mixtures.
Cost for utilisation of 1 ha of steep area on high altitude can be calculated as costs for hay harvest or costs for mountain grazing (day and night grazing, no indoor activity). Costs for hay harvest include one time cutting, drying and removal of the hay on steep meadows, while costs for mountain grazing comprise fencing activities and supervision of the animals for one summer season. Calculation relate to standard procedures and standard costs and no national payments (e.g. Austrian environmental payments) are deducted.
The set up costs indicate that commercial seed mixtures would be much cheaper than seed mixtures including indigenous species. But when looking at the years following the set up the sites that use commercial seed mixtures have to calculate with follow up costs (reseeding and steady fertilisation). So in the long term in order to reach a sustainable

restoration the use of indigenous species is not only from an ecological but also from an economical standpoint meaningful.
Concerning the application technique, plain hydroseeding is the cheapest method even if there is a 60 % chance that the whole application has to be repeated because of heavy surface runoff and soil losses and as a consequence a bad vegetation coverage and unsatisfying restoration. Therefore from an ecological point of view strict rules to use application techniques that cover the top soil have to be adopted because enterprises always will try to use the economical cheapest technique which in that case could cause big problems with erosion.

Revenue from utilisation of the restored area via fodder production is given by calculating the milk production potential of the area. *Table 28* shows results from the Alperos project about yields and quality of the bio mass when the restored area is utilised (for more details see chapter 3.2.5). Since producing one kg fat corrected cow milk (FCM) consumes 3,20 MJ NEL, the milk production potential for 1 ha restored area is shown in the second and fourth column of *Table 28*.

Multiplying the amount of FCM by an average price for 1 kg FCM (0,30 €) results in the revenues for utilisation is shown in *Table 27*.
Taking into consideration that no transport and storing costs are calculated for the utilisation of hay clearly shows that mountain grazing is the only meaningful and economical way of utilisation. While there was not much difference concerning revenue between indigenous and commercial seed mixtures in application technique 1, 3 and 4, the commercial seed mixture was significant better in technique 2. On the other hand, revenue for technique 2 came off worst.

4. Conclusions

4.1 Seed production

The slow growing rate of the alpine grasses and forbs, their subsequently low competitive capacity and their susceptibility to fungal diseases make seed production difficult, especially in context with organic farming. Applications of herbicides and fungicides are indispensable for the seed production of alpine species. Therefore, seed propagation of alpine species according to the prescription of organic farming is very risky, expensive and not profitable at all.

As a general result of our investigations, an economical meaningful seed production is possible for the following indigenous species: *Avenella flexuosa, Deschampsia cespitosa, Festuca pseudodura, Festuca supina, Phleum alpinum, Phleum hirsutum, Poa violacea, Trifolium pratense ssp. nivale, Anthyllis vulneraria, Anthyllis alpestris* and *Leontodon hispidus*. Anyway, seed production of such species needs very experienced farmers. The demands on maintenance and chemical weed control are high, fluctuation in yield can be extreme. But on average, yields and product quality were observed to increase hand in hand with experience through the years. Therefore, our economic considerations are reflecting the current situation; the prospective for future seed production of indigenous species is better.

For the three species *Sesleria albicans, Trifolium alpinum, Trifolium badium*, successful seed production is not yet possible or economically meaningful. Further research work has to be carried out.

In Austria, commercial seed production of most of the investigated species was established during the last four years. Indigenous seed mixtures for different altitudes and site conditions are available on the market in the meantime.

4.2 High altitude restoration

Alpine ecosystems are characterised by unfavourable climatic conditions with limiting effects on growth and biomass production of plants that are increasing with altitude. At an altitude of 2000 m, the number of growing days (average daily temperatures > 5°C) is reduced to 67 days. In alpine environments, vegetation has a growing season of two to three months to establish. Because of the limited growing period, restoration activities at high altitudes have to be carried out in the first weeks after snow melt. During this period, most soils have a satisfying water content, also on exposed sites. The results of our investigations on climatic site conditions also indicate that large scale interventions and thus restoration with seed mixtures generally should be avoided above altitudes of 2.400 m.

The conservation of the top soil as substrate is important for an enrichment of indigenous plants deriving from restoration, as their seed cannot be obtained on the market or it is very expensive. Our results indicate that even after a partial mixing of the top soil with mineral layers which are devoid of a seed bank, seed densities can be considerable. Therefore, conservation of the top soil should therefore be regarded as a very important task planning restoration. Discarding the top soil during the construction of a ski slope represent a waste of valuable autochthonous plant material which is available in place for a site-specific, low-impact restoration.

Results of several earlier assessments indicate that, up to altitudes of 1.800 – 2.000 m, a minimum vegetation cover of 70 % is required to avoid erosion. Above, more dense

vegetation with a cover of about 80 % is recommended. Therefore, a sufficient combination of application technique and adapted seed mixture, reaching the minimum requirement of a sustainable vegetation with 70 to 80 % cover within the first two vegetation periods has to be the goal behind restoration in high altitudes. Our assessment on vegetation cover of the plots showed that, under average conditions of high altitudes, the necessary minimum demand on cover can be achieved in the second vegetation period at the earliest. This requires application techniques with sufficient protection of top soil for the first two vegetation periods.
The comparison of different application techniques during our assessments on erosion and surface runoff in the weeks after restoration showed clear results. Only an additional cover of the top soil is able to reduce surface runoff and soil losses to an acceptable degree. A lot of different techniques are available which would guarantee a sufficient protection of top soil like straw mulching, hay mulching, different mats, nets, three-dimensional mats etc. The use of application techniques enabling a satisfying cover of top soil should be generally recommended for restoration of slopes at high altitudes.
A comparison of three different application techniques at each site, assessed for the whole project period, showed comparable results for plain hydroseeding and techniques with covered top soil looking at the vegetation cover. Only the technique hydroseeding combined with mycorrhiza inoculum exhibited significant lower cover values in the first two growing seasons. Taking into account the results of our erosion trials, the use of mycorrhiza combined with extensively minimised or no fertilisation would be an alternative to the commonly used chemical or organic fertilisers, provided that it is combined with an additional cover of the top soil like on locations Zillertal and Bayrischzell. As the straw cover was the only difference between the two treatments where mycorrhiza was employed, the higher vegetation cover achieved where the straw cover was used provides evidence for the short-term beneficial effect on seedling establishment. Due to the better protection against surface runoff and soil erosion during the first two vegetation periods, only the techniques with additional cover of the top soil can be recommended.

An overall statistical assessment of all locations showed significant better cover of indigenous seed mixtures, beginning in the third growing season. The results obtained give a clear answer to the necessity of using indigenous seed mixtures. Except for site Zillertal, indigenous seed mixtures were able to reach the minimum demands of vegetation cover with a single fertilization. For practical use, these results should establish a new state of the art in restoration and maintenance expenditure, leading to a clear reduction of expenses. The widespread argument that fast - growing components of commercial species and in principle steady fertilization for some years are needed to enable a fast protection against erosion, cannot be confirmed by the results.
The results also indicate the differences between sites and development of single species. For practical use, a stipulated composition of indigenous seed mixtures should be avoided. The more extreme the site conditions and the larger the restoration area, the more important is a specific site - according composition of the seed mixture, created by an expert.

A classification of mixtures referring to the ecological value of the assessed species was used for this report. Summarizing the valuable groups with expected sustainability, indigenous seed mixtures reached the minimum requirement of 70 % cover. In comparison, the share of valuable groups from the commercial mixture remained below

45 %, containing about 10 % indigenous species immigrated from plots with indigenous seed mixtures. Furthermore, indigenous species were able to maintain their original share. In the commercial mixture, the share of not adapted species decreased from 50 % to about 20 %, mainly at the expense of total cover. For practical use, the results clearly indicate that commercial seed mixtures containing a high percentage of species that are not adapted to site conditions would lead to the necessity of repeated seeding and fertilization to reach a vegetation cover securing sufficient protection against erosion. In a long - term estimation, it can be assumed that the lack of sustainable indigenous species will cause steady efforts, especially in altitudes above 1.800 m.

The assessment of fertility showed that commercial lowland species with single exceptions are not able to get fertile in altitudes above 1.800 m. Under average climatic conditions during the growing season, most indigenous alpine species are able to produce ripe seeds up to altitudes of about 2.200 m. This is a very important condition for an enrichment of the seed bank, supporting an independent regeneration of vegetation in case of damage. On most sites, a significant higher number of species was found on plots with indigenous vegetation, also reflecting a higher ecological value resulting from the use of indigenous seed mixtures. Grouping main species referring to their ecological value, it is also evident that the roots of indigenous and adapted species in general show higher tensile strength. Therefore, better resistance against mechanical damage caused by cattle, preparation of ski runs or tourists can be expected.

In some parts of the Alps, the use of ski runs and other restored areas is of great importance for agricultural use (mainly for grazing cattle and sheep). Dry biomass yield from restored sites in high altitudes is comparable to alpine pastures, assuming that available humus was stored sufficiently and applicated again. In general, commercial and indigenous seed mixtures have comparable yield. Digestibility as one of the main characteristics of forage quality showed a decrease with increasing altitudes, while the content of fibre increased. In comparison to commercial mixtures, a significant reduction of digestibility is possible, reflecting the faster development of pre-alpine and alpine species.

The set up costs indicate that commercial seed mixtures would be much cheaper than seed mixtures including indigenous species. But looking at the years following the set up the sites that used commercial seed mixtures, follow up costs (reseeding and steady fertilisation) have to be calculated. In the long term, in order to reach a sustainable restoration, the use of indigenous species is meaningful, not only from an ecological but also from an economical point of view.

Concerning an evaluation of the main application techniques, plain hydroseeding is the cheapest method. Even if there is a 60 % chance that the whole application has to be repeated because of heavy surface runoff and soil losses and, as a consequence, a bad vegetation coverage and unsatisfying restoration. Therefore, from an ecological point of view, strict rules to use application techniques that cover the top soil have to be adopted because enterprises always will try to use the economical cheapest technique which in that case could cause big problems with erosion.

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Table 1: **Important characteristics of the analysed species**

species	distribution	vegetation belt montane	subalpine	alpine	parent rock silicious	calcareous	moisture dry	wet
grasses								
Avenella flexuosa	world-wide	+	+	+	+	-	+	(-)
Deschampsia cespitosa	world-wide	+	+	+	+	+	(-)	+
Festuca nigrescens	europe, montane-alpine	+	+	+	+	+	+	+
Festuca pseudodura	middle-europe, pre-alpine, alpine	-	(+)	+	+	(-)	+	(-)
Festuca supina	middle-europe, pre-alpine, alpine	-	+	+	+	(-)	+	(-)
Phleum alpinum	middle-south-europe, montane-alpine	(+)	+	+	+	(+)	(+)	+
Phleum hirsutum	middle-south-europe, montane-alpine	(+)	+	+	(-)	+	+	(-)
Poa alpina	eurosib.-northam., montane-alpine	(+)	+	+	(+)	+	+	(+)
Poa violacea	europe, pre-alpine, alpine	-	+	+	+	(-)	(+)	(+)
Sesleria albicans	europe, kollin, montane-alpine	+	+	+	(-)	+	+	-
leguminosae								
Anthyllis alpestris	europe, montane-alpine	+	+	+	(-)	+	+	-
Anthyllis vulneraria	middle-south-europe, kollin, pre-alpine	+	(+)	-	(-)	+	+	-
Trifolium alpinum	west-europe, pre-alpine, alpine	-	(+)	+	+	-	(+)	(+)
Trifolium badium	middle-south-europe, pre-alpine-alpine	(+)	+	+	+	+	+	+
Trifolium pratense ssp.*nivale*	middle-south-europe, pre-alpine-alpine	-	+	+	+	(+)	(+)	+
herbs								
Leontodon hispidus	europe, kollin-alpine	+	+	+	(+)	(+)	(+)	(+)

species	distribution	tolerance against fertilisation	cutting	trampling	nutritional value	sward density
grasses						
Avenella flexuosa	world-wide	(-)	-	(-)	-	(-)
Deschampsia cespitosa	world-wide	+	(+)	+	-	(+)
Festuca nigrescens	europe, montane-alpine	+	+	+	(+)	+
Festuca pseudodura	middle-europe, pre-alpine, alpine	(+)	-	(+)	-	(+)
Festuca supina	middle-europe, pre-alpine, alpine	(+)	(-)	+	-	+
Phleum alpinum	middle-south-europe, montane-alpine	+	+	+	+	+
Phleum hirsutum	middle-south-europe, montane-alpine	+	+	+	(+)	+
Poa alpina	eurosib.-northam., montane-alpine	+	+	+	+	(+)
Poa violacea	europe, pre-alpine, alpine	(+)	(+)	(+)	(-)	(+)
Sesleria albicans	europe, kollin, montane-alpine	(-)	(-)	(-)	(-)	(-)
leguminosae						
Anthyllis alpestris	europe, montane-alpine	(+)	(-)	(+)	(-)	-
Anthyllis vulneraria	middle-south-europe, kollin, pre-alpine	(+)	(-)	(+)	(-)	-
Trifolium alpinum	west-europe, pre-alpine, alpine	+	+	+	+	-
Trifolium badium	middle-south-europe, pre-alpine-alpine	(+)	+	+	+	(-)
Trifolium pratense ssp.*nivale*	middle-south-europe, pre-alpine-alpine	(+)	+	+	+	(-)
herbs						
Leontodon hispidus	europe, kollin-alpine	(+)	(+)	+	(+)	(-)

+ = very good, (+) = good, (-) = poor, - = very poor

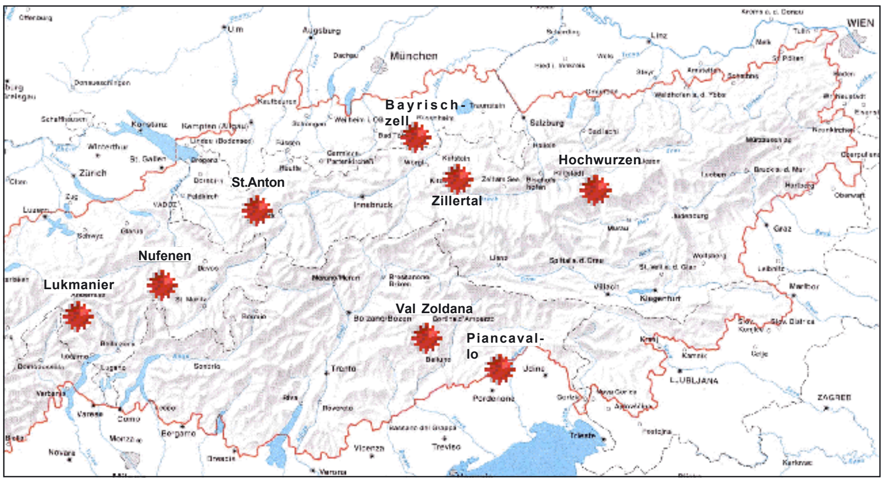

Figure 1: **Project ALPEROS, locations of the trials**

Table 2: **Description of sites**

	Bayrischzell	Piancavallo	Val Zoldana	Hochwurzen	Zillertal	St. Anton
altitude	1230	1435	1660	1830	2280	2350
gradient	15°	32°	20°	26°	13°	22°
exposition	N	SO	NNO	SO	S	SSO
parent rock	main dolomite	limestone	blackish ladinical tufa	gneiss	quarzphyllit	silt stone limestone
soil type	pseudo-gleyfied brown rendsic leptosol and pseudofied cromic cambisol	brown rendsic leptosol	gleyic cambisol	leptosol	alpine planosol	cambisol, pseudo-gleyfied brown leptosol and rendsic leptosol
surrounding vegetation	Crepido-Cynosuretum	Dentario pentaphylli-Fagetum sylvatioae	Larici-Piceetum adenostyletosum	Sieversio-Nardetum strictae vaccinietosum myrtilli	Seslerio-Caricetum sempervirentis Hygrocaricetum curvulae	Sieversio-Nardetum strictae
pH	6,9	7,1	6,2	6,6	4,9	6,9
humus (%)	8,23	1,10	4,33	4,00	5,67	4,7
$CaCO_3$ (%)	23,9	27,07	30,57	9,2	5,9	16,17
N total (%)	0,44	0,27	0,17	0,21	0,27	0,25
P_2O_5 (mg 100 g^{-1})	<3	<3	<3	<3	5	3,67
K_2O (mg 100 g^{-1})	6,67	7,67	9,67	5,67	<3	8,67

Table 3: **Climatical characteristics of the sites (average of vegetation period from 1st June to 31st August)**

	Bayrischzell	Piancavallo	Val Zoldana	Hochwurzen	Zillertal	St. Anton
altitude	1230	1435	1660	1830	2280	2350
sum of precipitation	578	862	519	690	641	1314
air temperature 200 cm ag *	13,95	12,69	12,47	10,52	8,1	7,31
air temperature 5 cm ag	15,71	14,83	14,08	13,44	9,7	8,75
soil temperature 2cm ug **	14,88	14,81	15,08	13,08	11,4	7,90
soil temperature 15 cm ug	13,91	12,30	14,14	12,11	10,6	7,41

* above ground ** below ground

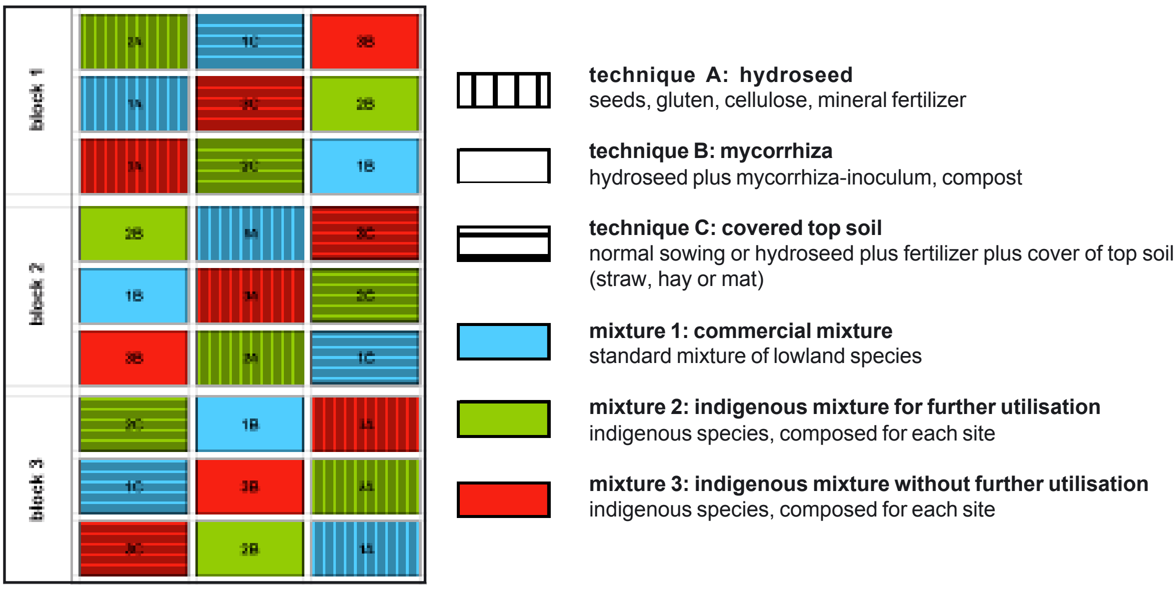

Figure 2: **Common trial design of project Alperos**

Table 4: **Description of application techniques for all sites**

Material		Application technique A - plain hydroseeding	Application technique B - hydroseeding with Mycorrhiza	Improved technique CB Bayrischzell hydroseeding with Mycorrhiza plus straw	Improved technique CP Piancavallo normal seeding plus „Curasol AK“ and straw	Improved technique CV Val Zoldana hydroseeding plus „Curlex“	Improved technique CH Hochwurzen normal seeding plus straw mat „S 100 Greenfield“	Improved technique CZ Zillertal technique 2 plus straw	Improved technique CS St. Anton hydroseeding plus hay
Cellulose	g m^{-2}	80				80			
Curasol (glutener)	g m^{-2}	15				15			
Curlex tridimensional mat	g m^{-2}					500			
Hay	g m^{-2}								500
Mature compost	g m^{-2}		80	80			1355	80	
Mineral fertiliser (15:15:15)	g m^{-2}	20			20	20			
Mineral fertiliser (Hyperkorn, 26% P205)	g m^{-2}						15		
Mineral fertiliser (Nitroform)	g m^{-2}						7,9		
Mineral fertiliser (Recuform)	g m^{-2}	5							
ONSM (provide verde, organic nutrient conveyor)	g m^{-2}		65	65				65	
Organic fertiliser (Maltaflor long term fertiliser)	g m^{-2}								250
Organic glutener (Ekotac GP Plus)	g m^{-2}								25
OSFA (organic glutener)	g m^{-2}		3,5	3,5				3,5	
Sanoplant SM3 (mineral powder - water and nutrient store)	g m^{-2}				100				
Seeds	g m^{-2}	15	15	15	15	15	15	15	15
Seeds (cover crop summer rye)	g m^{-2}								10
Straw	g m^{-2}			500	500			500	
Straw mat	g m^{-2}						350		
VAMF (mycorrhiza inoculum)	ml m^{-2}		65	65				65	

Table 5: **Composition of seed mixtures for all sites (% weight)**

species	commercial mixture	indigenous mixture for further utilisation Bayrischzel	indigenous mixture without further utilisation Bayrischzel	indigenous mixture for further utilisation Piancavallo	indigenous mixture without further utilisation Piancavallo	indigenous mixture for further utilisation Val Zoldana	indigenous mixture without further utilisation Val Zoldana	indigenous mixture for further utilisation Hochwurzen	indigenous mixture without further utilisation Hochwurzen	indigenous mixture for further utilisation Zillertal	indigenous mixture without further utilisation Zillertal	indigenous mixture for further utilisation St. Anton	indigenous mixture without further utilisation St. Anton
grasses													
Agrostis capillaris	4,6							4		6	8		
Avenella flexuosa					10		5		5	6	6		5
Deschampsia cespitosa									5		5		2
Festuca nigrescens		28	20	15	28	20	28	35	35	22	29	40	40
Festuca norica									5				4
Festuca ovina	2,5		10									5	
Festuca pseudodura									5				10
Festuca rubra	31												
Festuca supina									5	5	7		
Lolium perenne	15,7					10		3					
Phleum alpinum		5	5	5		10	10	10	5	6		5	
Phleum hirsutum		10	5	15	10	25	15					5	3
Phleum pratense	19,9												
Poa alpina		25	25	30	15	5		15	10	27	20	20	10
Poa pratensis	10,6												
Poa supina		5	5	5				5		4	4	5	
Poa violacea		10	10					5	5				5
Sesleria albicans					12		12					2	1
leguminosae													
Anthyllis vulneraria		3	4		10	10	10	5	5			5	5
Lotus corniculatus	5	3	4	5	5	5		3		6	7	2	2
Trifolium badium		1	2	5	5		10	5	5	2	2	5	4
Trifolium hybridum	2,4									6		2	
Trifolium montanum									1				1
Trifolium pratense ssp. *nivale*								7	5			1	2
Triolium repens	4,2	6	6	15		10	5			6	7		
Vicia sativa	3,4												
herbs													
Achillea millefolium	0,7				3		2	1	1	2	2	2	1
Campanula barbarta								0,22	0,34		0,5		
Crepis aurea		0,1			0,1		0,1	0,5	0,25				
Dianthus superbus									0,25				
Leontodon hispidus		2	2	3		2	1	1	1	1	1	1	3
Silene dioica						1	1	0,03	0,16				
Plantago lanceolata		1,9			1,9								
Silene vulgaris			2	2		2	0,9	0,25	1	1	1,5		2

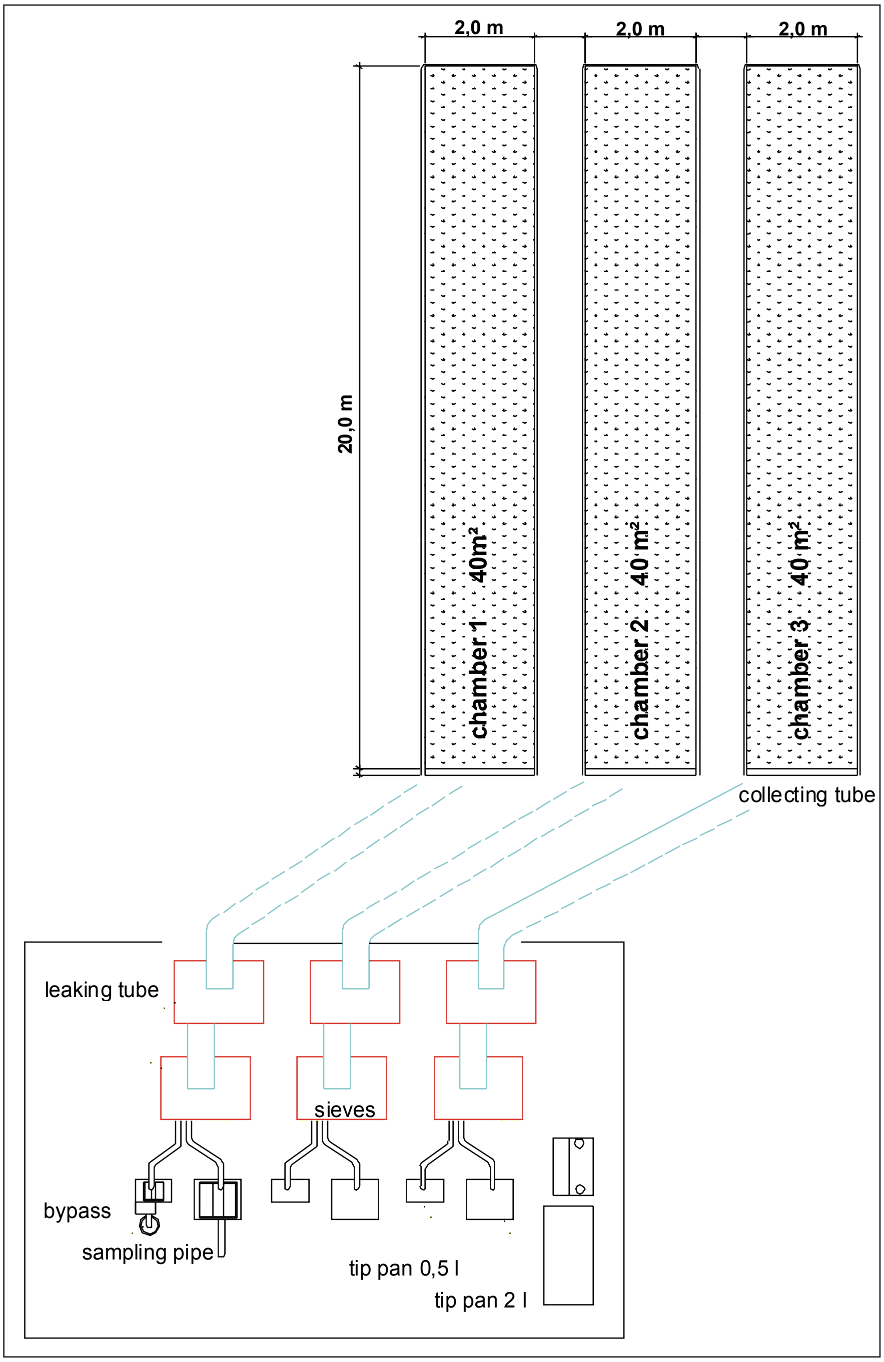

Figure 3: **Sketch of erosion facility „Hochwurzen“**

Table 6: **Overview of application techniques 1999 - 2002**

year	I	II	III
1999	hand sowing (commercial mixture)	hand sowing + straw mat (indigenous mixture)	hand sowing (indigenous mixture)
2000	hand sowing (indigenous mixture)	hand sowing (indigenous mixture) + cover grass (5% *Lolium perenne*)	hand sowing (indigenous mixture) + cover grass (70 kg ha^{-1} rye)
2001-2002	hand sowing (indigenous mixture)+ cover crop (70 kg ha^{-1} oat)	hydroseed (indigenous mixture; gluten, cellulose, seeds, organic fertilizer)	hydroseeding (indigenous mixture) straw mat

Table 7: **Characteristics for cultivation and fertilization**

specie	seed rate kg ha^{-1}	row spacing cm	fertilisation N	P_2O_5 kg ha^{-1}	K_2O	notes
grasses						
Avenella flexuosa	10 - 12	12 - 15	40	40	70	pH < 6 recommended
Deschampsia cespitosa	6 - 8	15 - 20	70	60	100	no cut after harvest
Festuca nigrescens	5 - 8	15 - 25	100	70	120	no cut between harvest and autumn
Festuca pseudodura	8 - 10	20	70	60	100	no cut between harvest and autumn
Festuca supina	6 - 8	15 - 20	70	60	100	no cut between harvest and autumn
Phleum alpinum	8 - 12	20 - 25	100	70	120	no cut between harvest and autumn
Phleum hirsutum	8 - 10	15 - 20	70	60	100	no cut between harvest and autumn
Poa alpina	6 - 8	15 - 20	100	70	120	no cut between harvest and autumn
Poa violacea	8 - 10	15 - 20	70	60	100	-
Sesleria albicans	14 - 16	20 - 25	40	40	70	low growth rate
leguminosae						
Anthyllis alpestris	8 - 10	20 - 45	-	70	120	-
Anthyllis vulneraria	8 - 10	20 - 45	-	70	120	-
Trifolium alpinum	10 - 14	12 - 24 or 45	-	40	70	nematode-free soils, pH < 5,5 recommended
Trifolium badium	10 - 12	15 - 20	-	40	70	low growth rate
Trifolium pratense ssp. *nivale*	8 - 12	20 - 25	-	70	120	cut in spring recommended
herbs						
Leontodon hispidus	10 - 12	15 - 20	40	40	70	2 harvests per year

Table 8: **Possibilities of chemical weed control in seed production of indigenous species**

specie	active substance	e.g. trade name	appl. rate ha^{-1}		time application
grasses in general	Tribenuron-methyl + Fluroxypyr	Express + Starane 250 EC	15 g + 0,5 l	p.e.*	dicotyledons
	Bromoxynil + Ioxynil	Oxytril	1,5 l	p.e.	dicotyledons
	Bentazone	Basagran	2 l	p.e.	dicotyledons
	Fluroxypyr	Starane 250	0,5 l	p.e.	dicotyledons
	MCPP + Bromoxynil + Ioxynil	Aniten new	2 l	p.e.	dicotyledons
	Bentazone + 2,4-DP	Basagran DP	4 l	p.e.	dicotyledons
	Dicamba + MCPA	Banvel M	4 l	p.e.	dicotyledons
	MCPP + 2,4-D	Dicopur U 46 KV new	4 l	p.e.	dicotyledons
	MCPP	Duplosan KV	2 l	p.e.	dicotyledons
	MCPA	Dicour M	2 l	p.e.	dicotyledons
	2,4-D	Dicopur fluid	1 l	p.e.	dicotyledons
	Clopyralid + Triclopyr	Garlon L 60	2,5 l	p.e.	dicotyledons
	Ethofumesat	Tramat	1,5 l	p.e.	dicotyledons, monocotyledons
Festuca ssp.	Cycloxydim	Focus ultra	2 - 3 l	p.e.	grasses
	Quizalofop	Targa super	1 l	p.e.	grasses
Anthyllis ssp.	Bentazone + 2,4 OP	Basagran DP	2 l + 1 l	plants> 10 cm	dicotyledons
	Oxasulfuron		100 g	over 2 - 4 leaves stadium	
	Imazethapyr + ammonic sulfate		1,5 l + 4 l	over 2 - 4 leaves stadium	
	Acifuorfen		0,5 l	over 2 - 4 leaves stadium	
Trifolium pratense ssp. *nivale* + *Trifolium badium*	Bentazone	Basagran	2 l	over 2 leaves stadium	dicotyledons
	Quizalofop	Targa super	1,5 l	over 2 - 4 leaves stadium	grasses
	Fluorzifop-P	Fusilade extra	2 l	p.e.	grasses

* p.e.: post emergence

Table 9: **Harvest, yield and seed quality of the investigated species**

specie	period of harvest	number of harvesting years	average yield 1st harvest kg ha^{-1}	average yield 2nd harvest kg ha^{-1}	yield kg ha^{-1}	TSW** g	GC*** %	purity %
grasses								
Avenella flexuosa	28.06. - 10.07.	2 - 3	120	80	12 - 150	0,75	86	97
Deschampsia cespitosa	01.07. - 15.07.	2 - 5	120	200	60 - 300	0,26	85	99
Festuca nigrescens	15.06. - 15.07.	2 - 3	700	500	400 - 900	1,13	88	94
Festuca pseudodura	23.06. - 04.07.	2 - 3	350	300	110 - 400	0,95	82	95
Festuca supina	05.07. - 15.07.	2 - 3	180	350	120 - 470	0,52	82	97
Phleum alpinum	28.06. - 12.07.	1 - 2	200	120	20 - 280	0,50	75	91
Phleum hirsutum	18.07. - 28.07.	1 - 2	80	110	20 - 180	0,30	70	99
Poa alpina	15.06. - 30.06.	2 - 3	300	350	180 - 450	0,42	80	94
Poa violacea	18.06. - 02.07.	1 - 3	150	200	60 - 450	0,35	75	95
Sesleria albicans	25.05. - 10.06.	1 - 2	40	60	15 - 120	1,60	75	98
leguminosae								
Anthyllis alpestris	01.08. - 10.08.	1 - 2	150	0	80 - 370	3,34	92	96
Anthyllis vulneraria	05.08. - 18.08.	1 - 2	300	260	120 - 400	3,28	94	97
Trifolium alpinum	01.07. - 12.07.	1 - 2	10	20	0 - 40	5,00	70	98
Trifolium badium	23.06. - 04 07.	1	70	0	21 - 80	0,98	78	98
Trifolium pratense ssp. *nivale*	25.07. - 30.08.	2 - 3	100	120	10 - 120	1,10	72	97
herbs								
Leontodon hispidus 1st harvest	09.06. - 26.06.	2 - 4	80	100	60 - 180*	1,35	73	96
2nd harvest	15.08. - 15.09.							

* two harvests per year ** thousand seed weight *** germination capacity

Table 10: **Proposal for minimum demands on seed quality**

	water content (%)	minimum purity (% weight)	maximum content of foreign species (% weight)	maximum content single specie (% weight)	minimum germinative capacity (%)
grasses					
Avenella flexuosa	14	85	2,0	1,5	75
Deschampsia cespitosa	14	90	1,5	1,0	75
Festuca nigrescens	14	90	2,0	1,5	80
Festuca pseudodura	14	90	2,0	1,5	80
Festuca supina	14	90	2,0	1,5	80
Phleum alpinum	14	75	3,0	2,0	70
Phleum hirsutum	14	95	1,5	1,0	70
Poa alpina	14	85	2,0	1,5	75
Poa violacea	14	85	2,0	1,5	75
Sesleria albicans	14	90	1,5	1,0	70
leguminosae					
Anthyllis alpestris	12	97	1,5	1,0	80
Anthyllis vulneraria	12	97	1,5	1,0	80
Trifolium alpinum	12	97	1,5	1,0	75
Trifolium badium	12	97	2,0	1,0	80
Trifolium pratense ssp. *nivale*	12	97	2,0	1,0	80
herbs					
Leontodon hispidus	14	90	2,0	1,5	70

Table 11: **Proposal for seed testing rules according to ISTA**

	substrate	temperature	first count (days)	last count (days)	additional remarks
grasses					
Avenella flexuosa	TP	15, 20-30, 20	7	16	prechill, KNO_3
Deschampsia cespitosa	TP	20-30, 20	7	16	prechill, KNO_3
Festuca nigrescens	TP, PP	15-25, 20-30, 20	7	21	prechill, KNO_3
Festuca pseudodura	TP, PP	5-20, 15, 20	7	28	prechill, KNO_3
Festuca supina	TP, PP	15-25, 20	7	21	prechill, KNO_3
Phleum alpinum	TP, PP	15-25, 20	7	21	prechill, KNO_3
Phleum hirsutum	TP, PP	20-30, 20	7	21	prechill, $KNO_{3;}$ light
Poa alpina	TP, PP	15-25, 20	7	21	prechill, KNO_3
Poa violacea	TP, PP	15-25, 20	7	21	prechill, KNO_3
Sesleria albicans	TP, PP	15-25, 10-20, 20	7	21	prechill, KNO_3
leguminosae					
Anthyllis alpestris	TP, BP	15-25; 20	5	10	prechill
Anthyllis vulneraria	TP, BP	20	5	10	prechill
Trifolium alpinum	TP, BP	20	7	14	prechill, scarification
Trifolium badium	TP, BP	20	4	12	prechill
Trifolium pratense ssp.*nivale*	TP, BP	20	4	12	prechill
herbs					
Leontodon hispidus	TP, BP	20	7	14	prechill

*TP = top of paper, BP = between paper, PP = pleated paper

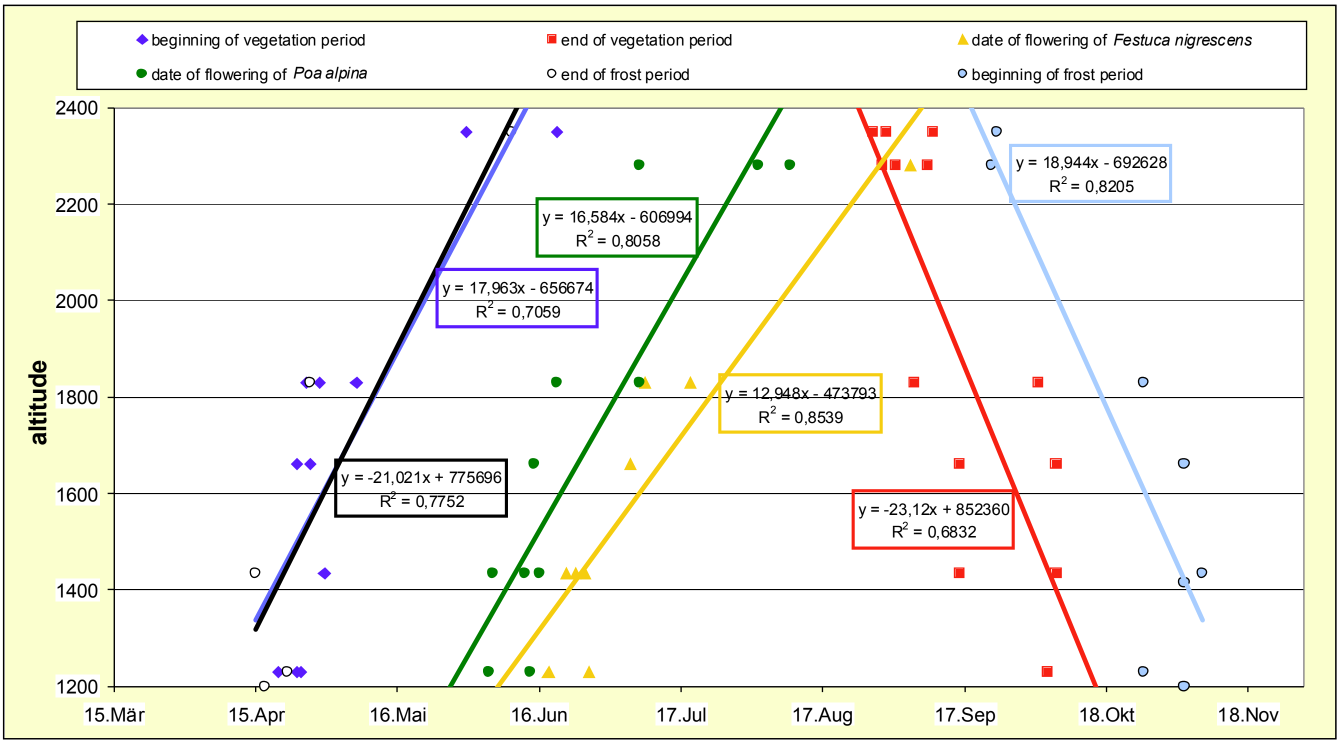

Figure 4: **Beginning and end of frost- and vegetation period, date of flowering of *Festuca nigrescens* and *Poa alpina* depending on altitude**

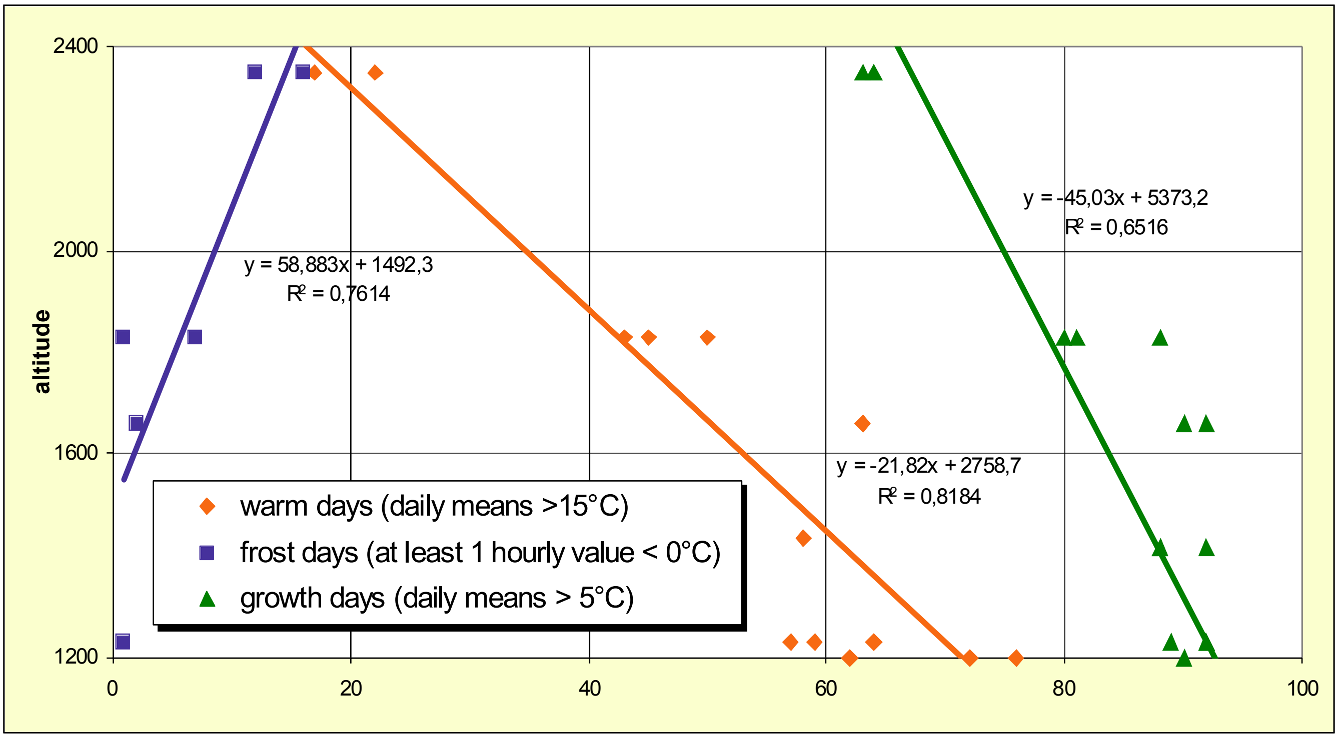

Figure 5: **Number of frost days, warm days and growing days depending on altitude**

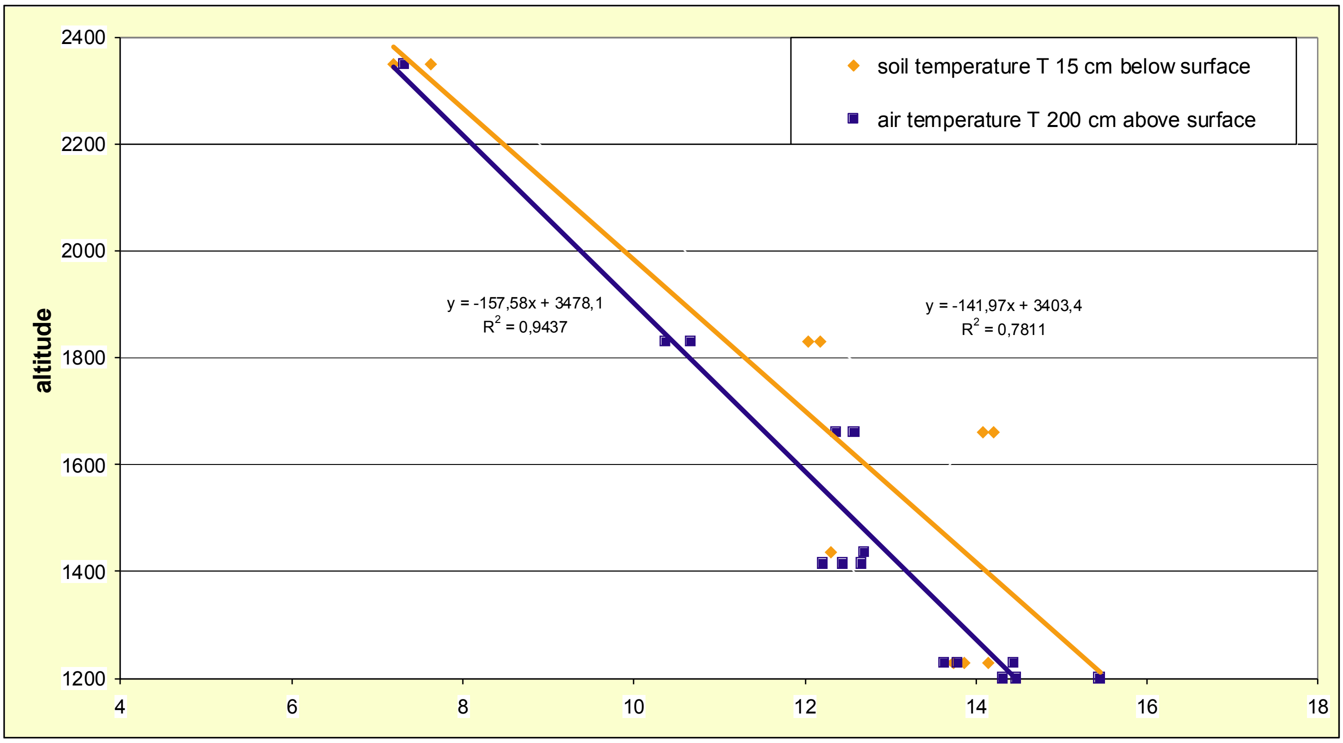

Figure 6: **Average means of air and soil temperature during the vegetation period (1st June - 31st August)**

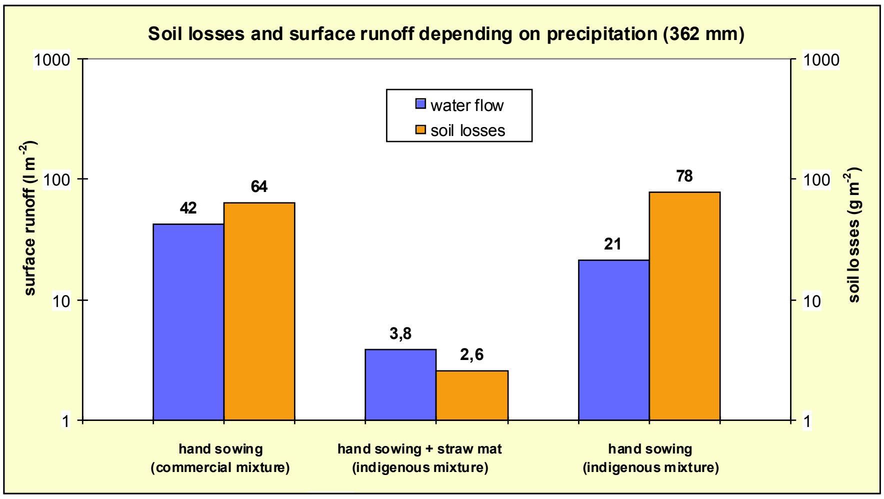

Figure 7: **Soil losses and surface runoff depending on precipitation (362 mm), observation period from 02-08-99 to 02-09-99**

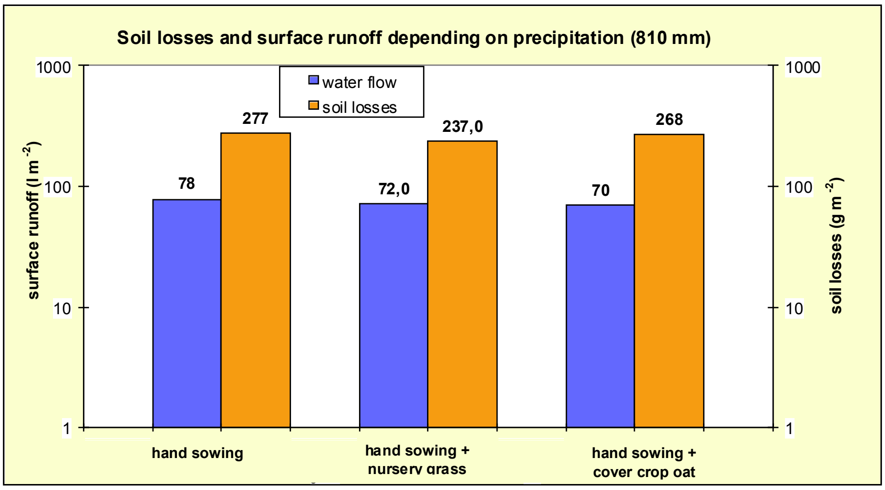

Figure 8: **Soil losses and surface runoff depending on precipitation (810 mm), observation period from 21-06-00 to 25-10-00**

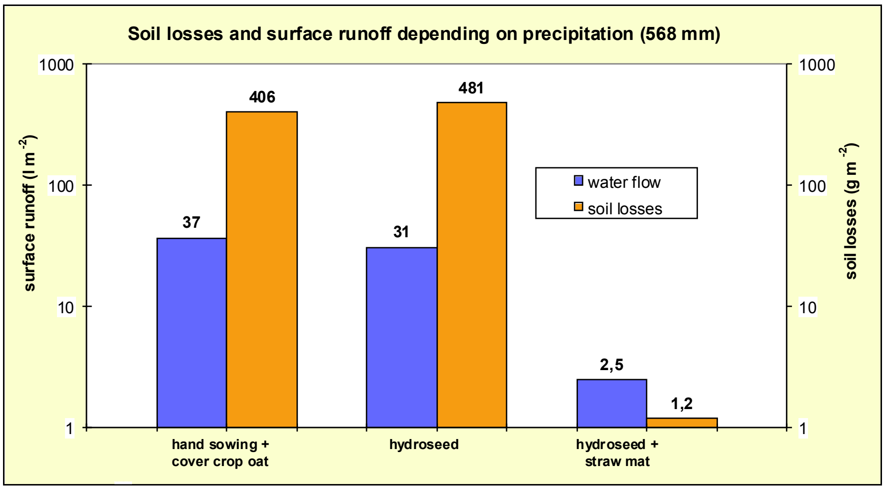

Figure 9: **Soil losses and surface runoff depending on precipitation (568 mm), observation period from 27-06-01 to 11-10-01**

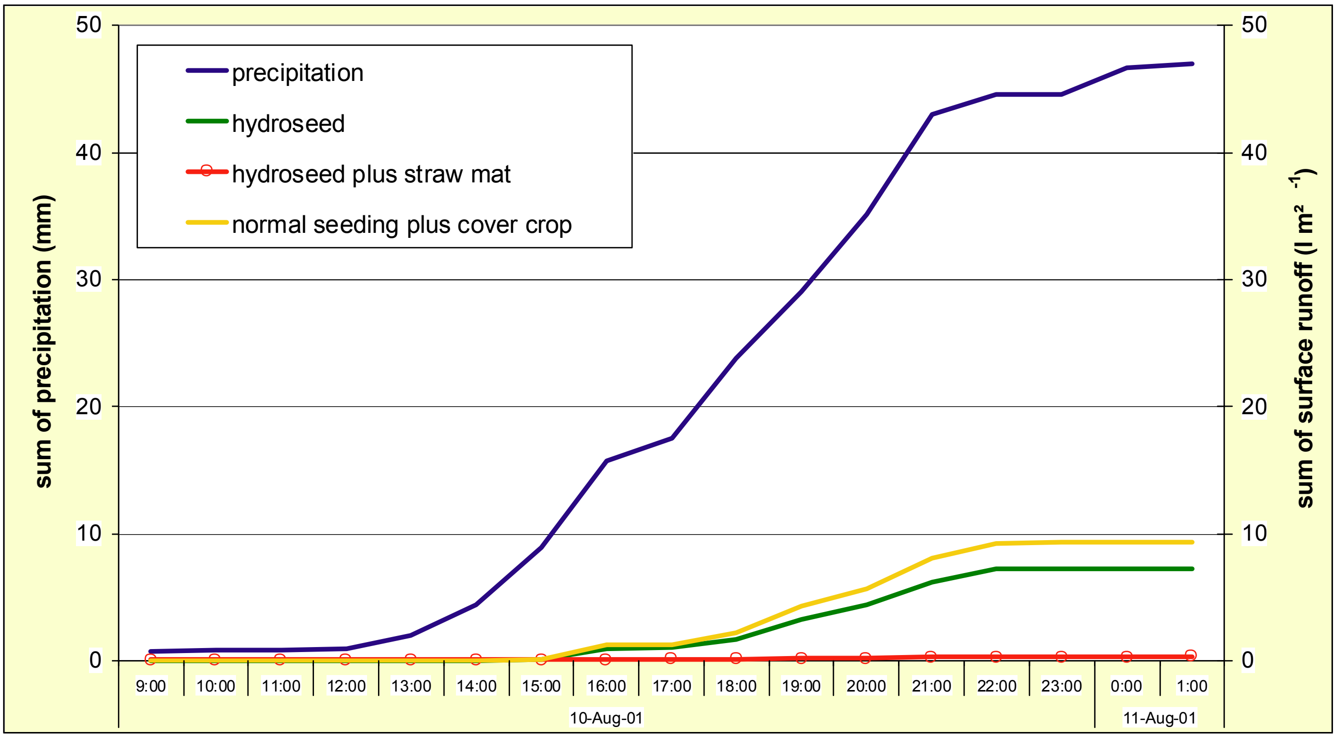

Figure 10: **Sum of precipitation and surface runoff in comparison of different application techniques during a raining event**

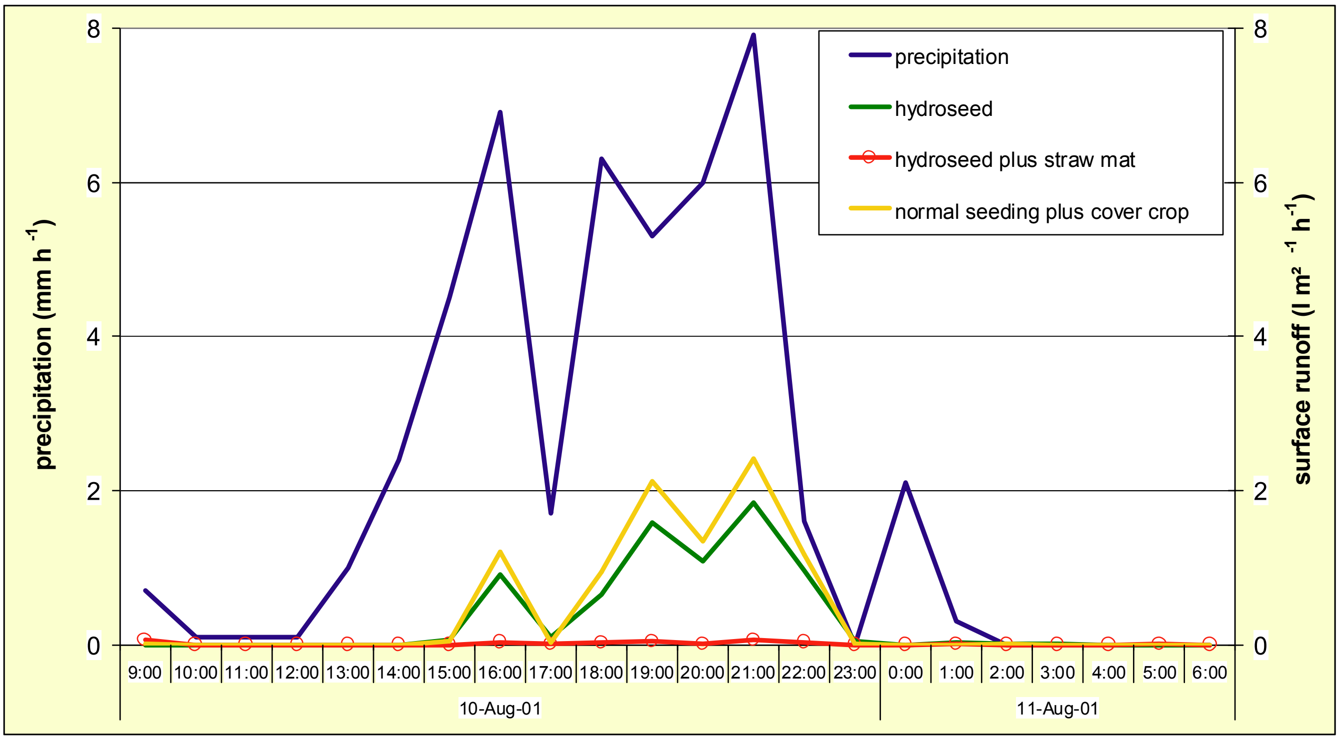

Figure 11: **Hourly values of precipitation and surface runoff in comparison of different application techniques during a raining event**

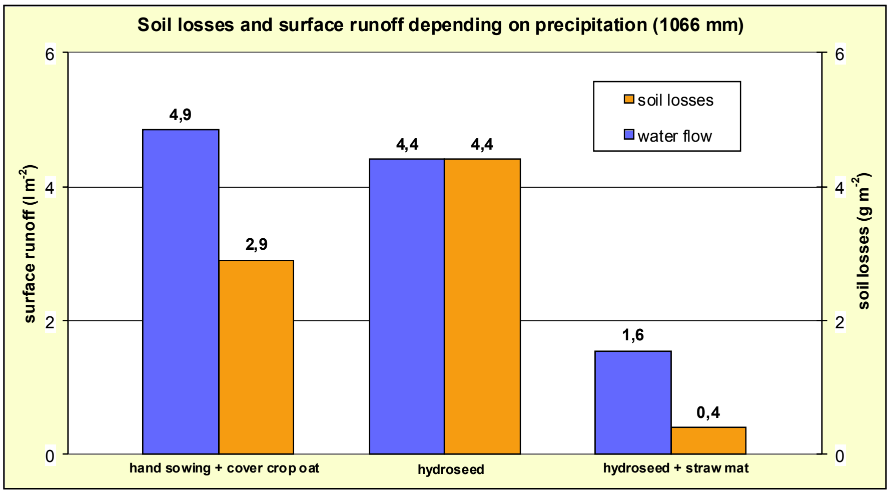

Figure 12: **Soil losses and surface runoff depending on precipitation (1066 mm), observation period from 23-05-02 to 28-08-02**

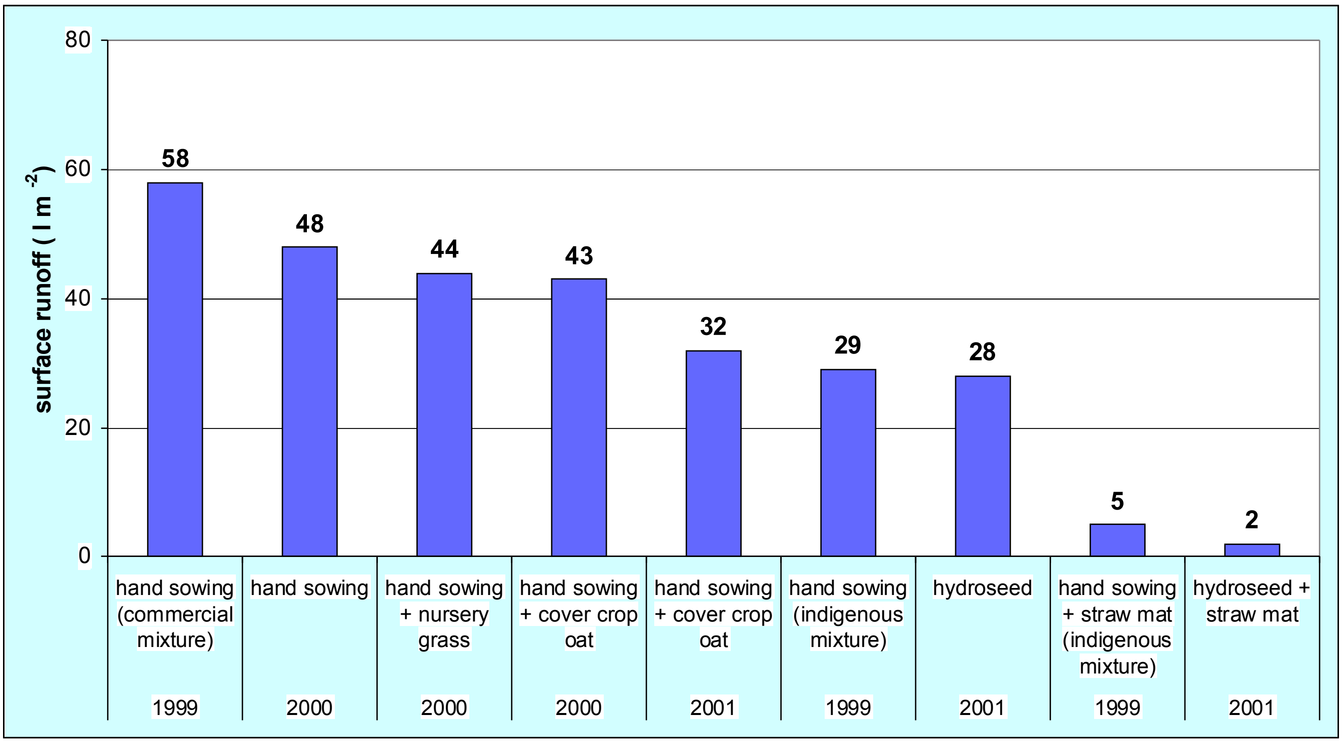

Figure 13: **Surface runoff referring to 500 mm precipitation, comparison of treatments and years (1999 - 2001)**

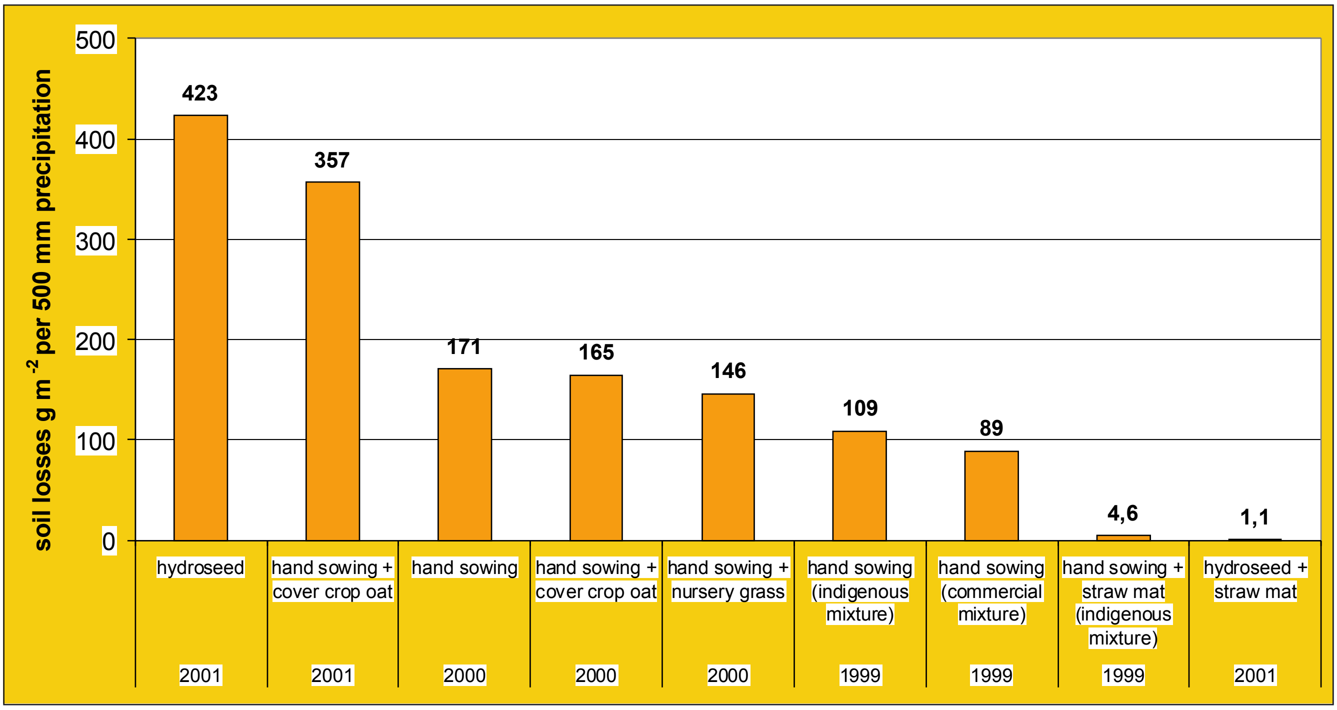

Figure 14: **Soil losses referring to 500 mm precipitation, comparison of treatments and years (1999 - 2001)**

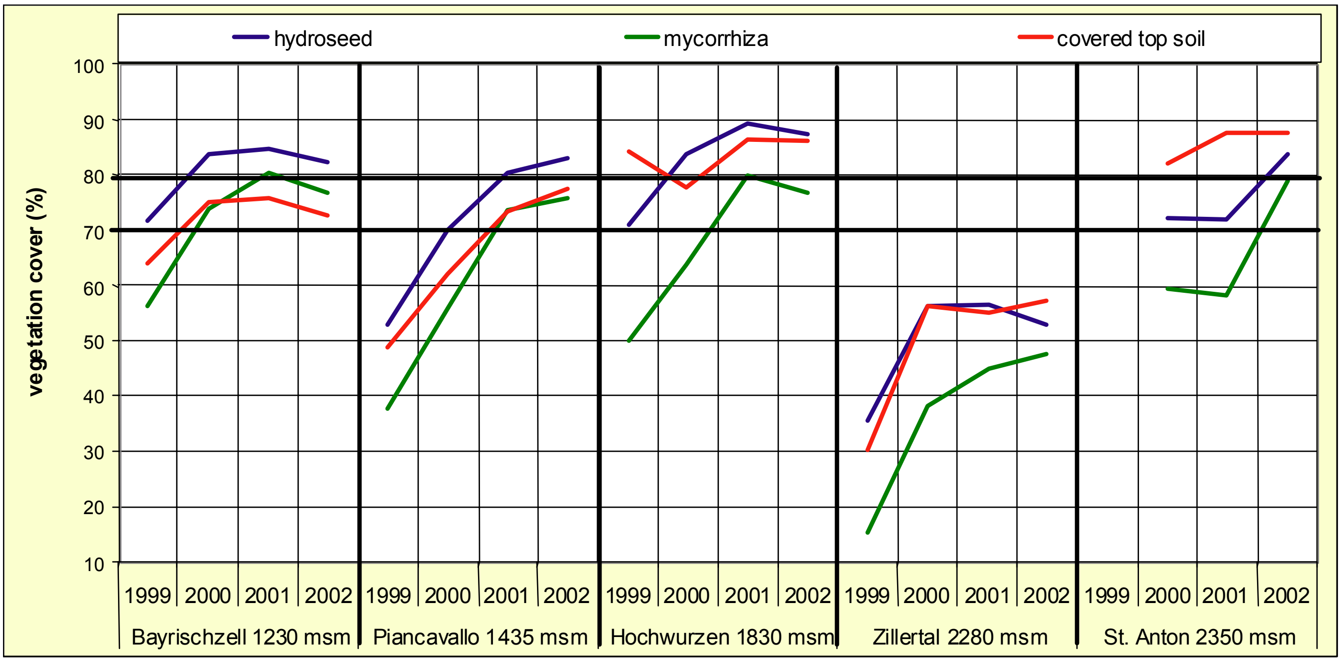

Figure 15: **Total vegetation cover in % depending on technique, comparison of sites and years**

Table 12: **Mean ranks and significance calculated with Kruskal-Wallis-test for total vegetation cover in %, comparison of techniques and mixtures, all sites and years**

grouping variable:		**application technique**				**seed mixture**			
		hydroseed	mycorrhiza	covered top soil	significance	commercial mixture	indigenous mixture with further utilisation	indigenous mixture without further utilisation	significance
1999	Bayrischzell	20,28	7,83	13,89	0,00	16,56	12,50	12,94	0,49
1999	Piancavallo	18,11	8,39	15,50	0,03	18,67	9,50	13,83	0,05
1999	Hochwurzen	14,06	5,11	22,83	0,00	15,56	14,61	11,83	0,58
1999	Zillertal	20,28	5,22	16,50	0,00	14,22	13,44	14,33	0,97
2000	Bayrischzell	20,11	9,56	12,33	0,01	13,22	14,22	14,56	0,93
2000	Piancavallo	18,89	9,72	13,39	0,05	15,94	11,39	14,67	0,45
2000	Val Zoldana	17,83	9,89	14,28	0,09	8,06	13,67	20,28	0,00
2000	Hochwurzen	19,94	6,28	15,78	0,00	8,00	17,22	16,78	0,02
2000	Zillertal	18,00	5,67	18,33	0,00	13,44	13,00	15,56	0,77
2001	Bayrischzell	16,94	13,11	11,94	0,38	9,11	16,56	16,33	0,08
2001	Piancavallo	16,78	12,89	12,33	0,43	12,50	12,72	16,78	0,44
2001	Hochwurzen	17,50	9,33	15,17	0,08	6,67	16,83	18,50	0,00
2001	Zillertal	16,44	9,72	15,83	0,14	8,44	16,83	16,72	0,04
2001	St. Anton	12,72	6,67	22,61	0,00	11,94	16,33	13,72	0,50
2002	Bayrischzell	16,00	14,44	11,56	0,48	6,78	19,22	16,00	0,00
2002	Piancavallo	16,94	12,33	12,72	0,39	13,39	13,11	15,50	0,78
2002	Hochwurzen	18,28	7,33	16,39	0,01	7,67	19,06	15,28	0,01
2002	Zillertal	13,89	10,72	17,39	0,20	9,78	16,39	15,83	0,15
2002	St. Anton	14,44	9,83	17,72	0,10	12,78	15,94	13,28	0,66

Table 13: **Residual cover % of application technique C, caused by geomats, curlex, straw or hay, comparison of 2000, 2001 and 2002**

		2000	**2001**	**2002**
Bayrischzell	commercial mixture	12,67	7,00	0,33
	indigenous mixture for further utilisation	9,00	4,00	0,00
	indigenous mixture without further utilisation	7,33	4,33	0,67
Piancavallo	commercial mixture	23,67	13,98	7,66
	indigenous mixture for further utilisation	23,67	9,84	7,92
	indigenous mixture without further utilisation	25,67	7,75	6,65
Hochwurzen	commercial mixture	18,67	no data	5,00
	indigenous mixture for further utilisation	5,33	no data	2,00
	indigenous mixture without further utilisation	8,67	no data	1,30
Zillertal	commercial mixture	21,33	16,83	6,00
	indigenous mixture for further utilisation	19,67	12,33	3,00
	indigenous mixture without further utilisation	17,33	13,33	4,33
St. Anton	commercial mixture	8,00	5,83	4,33
	indigenous mixture for further utilisation	10,67	3,17	4,00
	indigenous mixture without further utilisation	14,67	4,83	4,33
total average	**commercial mixture**	**14,94**	**12,10**	**3,67**
	indigenous mixture for further utilisation	**11,94**	**8,23**	**2,98**
	indigenous mixture without further utilisation	**12,28**	**8,72**	**3,20**

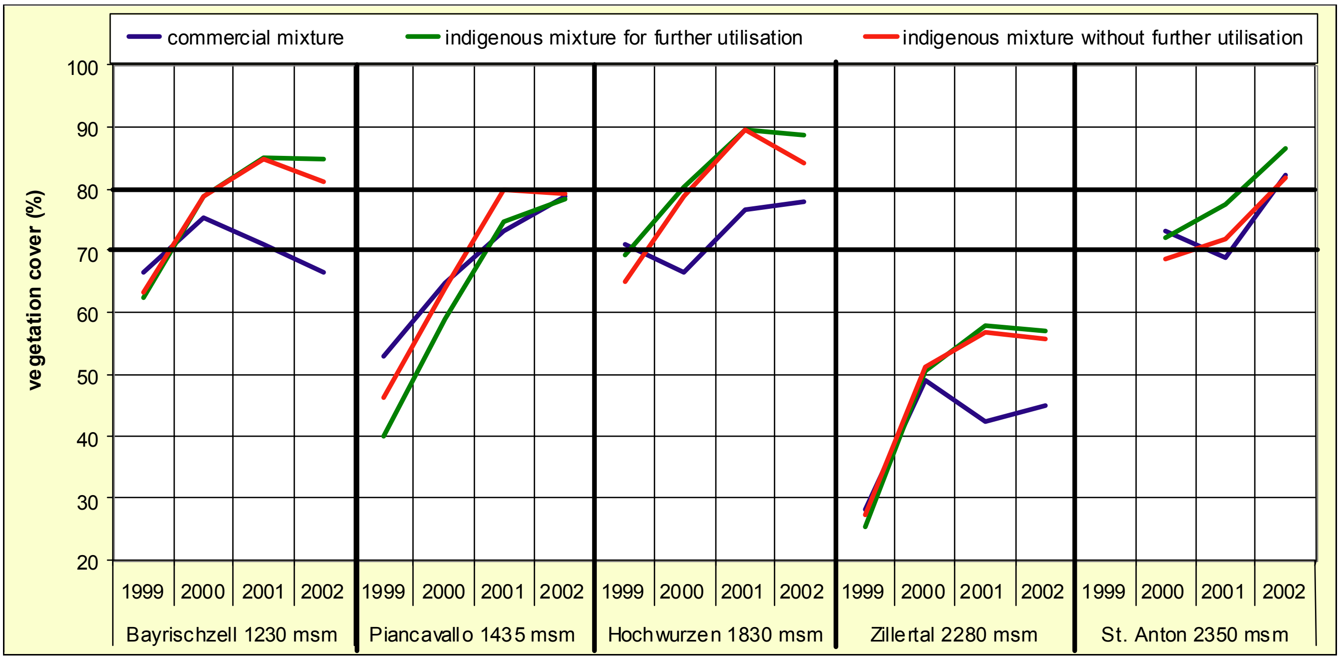

Figure 16: **Total vegetation cover in % depending on mixture, comparison of sites and years**

Table 14: **Total vegetation and share of grasses, leguminosae and herbs (cover in %) in the year 2002**

Total vegetation cover in % mixture	technique	Bayrischzell	Hochwurzen	Zillertal
commercial mixture	hydroseed	78	79	48
commercial mixture	mycorrhiza	63	74	41
commercial mixture	covered top soil	59	81	46
indigenous mixture with further utilisation	hydroseed	88	94	49
indigenous mixture with further utilisation	mycorrhiza	84	82	53
indigenous mixture with further utilisation	covered top soil	81	90	69

Grasses cover in % mixture	technique	Bayrischzell	Hochwurzen	Zillertal
commercial mixture	hydroseed	28	39	26
commercial mixture	mycorrhiza	24	33	35
commercial mixture	covered top soil	26	40	34
indigenous mixture with further utilisation	hydroseed	46	49	24
indigenous mixture with further utilisation	mycorrhiza	35	45	43
indigenous mixture with further utilisation	covered top soil	38	44	41

Herbs cover in % mixture	technique	Bayrischzell	Hochwurzen	Zillertal
commercial mixture	hydroseed	41	7	3
commercial mixture	mycorrhiza	35	6	3
commercial mixture	covered top soil	27	5	3
indigenous mixture with further utilisation	hydroseed	37	7	3
indigenous mixture with further utilisation	mycorrhiza	43	4	3
indigenous mixture with further utilisation	covered top soil	38	6	3

Leguminosae cover in % mixture	technique	Bayrischzell	Hochwurzen	Zillertal
commercial mixture	hydroseed	9	33	19
commercial mixture	mycorrhiza	4	34	3
commercial mixture	covered top soil	6	36	10
indigenous mixture with further utilisation	hydroseed	5	38	22
indigenous mixture with further utilisation	mycorrhiza	6	32	7
indigenous mixture with further utilisation	covered top soil	6	39	24

Table 15: **Vegetation cover in % of selected species of all sites, comparison of mixtures 2000 and 2002**

commercial mixture	year	*Achillea millefolium*	*Festuca ovina*	*Festuca rubra*	*Lolium perenne*	*Lotus corniculatus*	*Phleum pratense*	*Poa pratensis*	*Trifolium hybridum*	*Trifolium repens*
Bayrischzell	2000	3,1	1,2	7,1	9,9	2,3	20,3	1,0	2,8	6,8
	2001	3,9	0,3	10,0	2,1	1,4	14,3	0,5	2,0	5,1
	2002	7,1	0,1	8,8	0,4	0,4	7,2	0,1	2,1	2,7
Hochwurzen	2000	0,5	0,0	14,7	14,9	8,4	6,0	0,1	14,3	5,2
	2001	1,3	0,0	16,4	9,0	16,5	0,8	0,0	22,1	5,3
	2002	2,3	0,0	26,2	8,9	22,9	1,1	0,0	8,0	1,0
Zillertal	2000	0,6	0,0	12,7	15,9	1,4	7,1	0,1	4,8	2,1
	2001	0,8	0,0	13,1	2,1	0,5	9,6	0,0	4,3	1,9
	2002	1,1	0,0	11,7	0,1	0,1	10,2	0,0	6,4	2,6
Piancavallo	2000	0,6	0,9	14,7	15,0	1,4	8,4	1,1	4,6	4,3
	2001	4,8	1,4	14,7	9,5	4,3	9,4	0,8	7,1	3,6
	2002	8,0	4,3	28,6	1,1	9,6	6,4	0,7	4,9	0,2
Val Zoldana	2000	0,2	0,0	15,7	11,4	5,7	17,8	0,0	13,1	20,1
St. Anton	2000	2,2	0,0	5,7	27,2	1,7	21,4	0,5	4,9	1,1
	2001	6,2	0,4	11,1	0,0	0,5	33,8	0,0	6,2	0,1
	2002	7,9	0,4	9,1	0,1	0,5	35,9	0,0	7,7	1,1
total average	**2000**	**1,2**	**1,0**	**11,8**	**15,7**	**3,5**	**13,5**	**0,5**	**7,4**	**6,6**
	2001	**3,4**	**0,7**	**13,1**	**4,4**	**4,8**	**13,6**	**0,2**	**8,3**	**3,2**
	2002	**5,3**	**1,6**	**16,9**	**2,3**	**6,7**	**12,2**	**0,1**	**5,8**	**1,8**

indigenous mixture with further utilisation		*Achillea millefolium*	*Anthyllis vulneraria*	*Festuca nigrescens*	*Leontodon hispidus*	*Lolium perenne*	*Lotus corniculatus*	*Phleum alpinum*	*Poa alpina*	*Poa supina*	*Silene vulgaris*	*Trifolium badium*	*Trifolium pratense*
Bayrischzell	2000	0,5	0,7	7,9	9,1	0,5	1,4	3,4	12,3	3,3	0,1	1,4	0,0
	2001	1,4	0,6	10,2	10,1	0,2	1,5	3,3	11,8	1,9	0,2	1,1	0,0
	2002	2,9	0,3	13,6	15,1	0,0	1,1	4,8	5,9	0,4	0,2	0,5	0,0
Hochwurzen	2000	1,6	7,1	21,3	0,1	6,6	0,6	0,8	2,1	0,0	0,0	19,8	15,9
	2001	1,7	7,6	16,3	0,1	5,4	0,5	0,1	1,6	0,0	0,1	14,0	38,1
	2002	2,6	1,3	36,5	0,7	5,6	1,4	0,2	1,6	0,2	0,1	2,8	30,6
Zillertal	2000	1,3	0,3	16,3	0,3	2,3	0,3	0,3	6,5	0,8	0,3	3,8	0,0
	2001	1,1	0,0	17,9	0,2	0,3	0,1	0,6	10,9	2,7	0,4	10,1	0,0
	2002	1,5	0,0	18,8	0,3	0,0	0,0	0,7	8,9	1,0	0,2	12,4	0,0
Piancavallo	2000	0,0	1,1	10,3	2,1	1,6	2,1	0,2	11,6	0,6	4,2	1,8	0,0
	2001	0,6	0,7	14,8	7,5	0,6	1,4	0,9	18,1	0,4	6,4	0,9	0,0
	2002	1,3	1,4	14,6	10,3	0,0	1,5	1,1	18,4	0,0	10,0	0,3	0,0
Val Zoldana	2000	0,4	19,8	4,6	0,1	6,1	4,2	5,2	1,3	0,0	0,1	0,0	0,0
St. Anton	2000	5,0	0,3	26,7	0,3	1,6	0,2	0,6	15,4	0,0	0,1	5,0	1,7
	2001	7,1	0,0	19,9	0,3	0,0	0,2	0,3	22,2	0,0	0,2	14,6	0,0
	2002	7,1	0,0	19,8	0,6	0,0	0,1	0,8	17,7	1,6	0,3	27,9	0,0
total average	**2000**	**1,5**	**5,7**	**14,5**	**2,0**	**3,1**	**1,5**	**1,8**	**8,2**	**1,6**	**0,8**	**5,3**	**8,8**
	2001	**2,6**	**1,9**	**15,8**	**3,8**	**1,5**	**0,9**	**1,1**	**12,9**	**2,2**	**1,5**	**9,1**	**38,1**
	2002	**3,2**	**0,5**	**20,7**	**5,4**	**1,4**	**0,8**	**1,6**	**10,5**	**0,8**	**2,2**	10,6	15,3

indigenous mixture without further utilisation		*Achillea millefolium*	*Anthyllis vulneraria*	*Deschampsia cespitosa*	*Festuca nigrescens*	*Leontodon hispidus*	*Phleum alpinum*	*Poa alpina*	*Silene vulgaris*	*Trifolium badium*	*Trifolium pratense*
Bayrischzell	2000	0,5	2,1	0,7	7,1	5,9	4,3	9,6	7,0	5,0	0,0
	2001	1,5	0,4	1,5	10,2	9,0	3,4	8,6	9,7	1,7	0,0
	2002	2,6	0,2	1,4	12,1	8,9	4,4	3,6	10,7	0,4	0,0
Hochwurzen	2000	2,0	6,5	0,4	24,0	0,1	1,0	2,0	0,1	20,1	14,6
	2001	1,7	9,2	0,5	18,2	0,2	0,1	1,0	0,2	15,3	35,1
	2002	2,7	3,0	0,6	37,9	1,0	0,2	1,6	0,6	2,0	25,2
Zillertal	2000	1,4	0,0	2,3	18,8	0,2	0,2	6,1	0,3	3,8	0,0
	2001	0,9	0,0	3,5	17,5	0,2	0,2	10,7	0,2	8,0	0,3
	2002	1,6	0,0	6,1	17,6	0,2	0,2	7,5	0,2	9,3	0,0
Piancavallo	2000	4,1	24,8	0,0	12,4	0,0	0,0	10,0	0,4	1,6	0,0
	2001	15,8	14,5	0,0	12,8	0,0	0,0	13,8	1,1	0,6	0,0
	2002	16,9	7,2	0,0	15,4	0,3	0,0	16,9	2,1	1,0	0,0
Val Zoldana	2000	0,6	18,8	0,0	4,7	0,1	3,3	0,4	0,5	33,1	0,0
St. Anton	2000	3,4	0,3	0,3	26,8	0,5	0,2	13,2	3,0	3,8	3,0
	2001	4,7	0,0	0,6	20,5	0,5	0,0	21,9	3,6	10,9	0,0
	2002	4,7	0,0	0,7	17,7	0,5	0,2	20,1	3,2	22,7	0,0
total average	**2000**	**2,0**	**10,5**	**0,9**	**15,6**	**1,2**	**1,6**	**6,9**	**1,9**	**11,2**	**8,8**
	2001	**4,9**	**4,8**	**1,5**	**15,9**	**2,6**	**1,0**	**11,2**	**3,0**	**8,5**	**31,6**
	2002	**5,7**	**2,1**	**2,2**	**20,1**	**2,6**	**1,3**	**9,9**	**3,4**	**8,4**	**12,6**

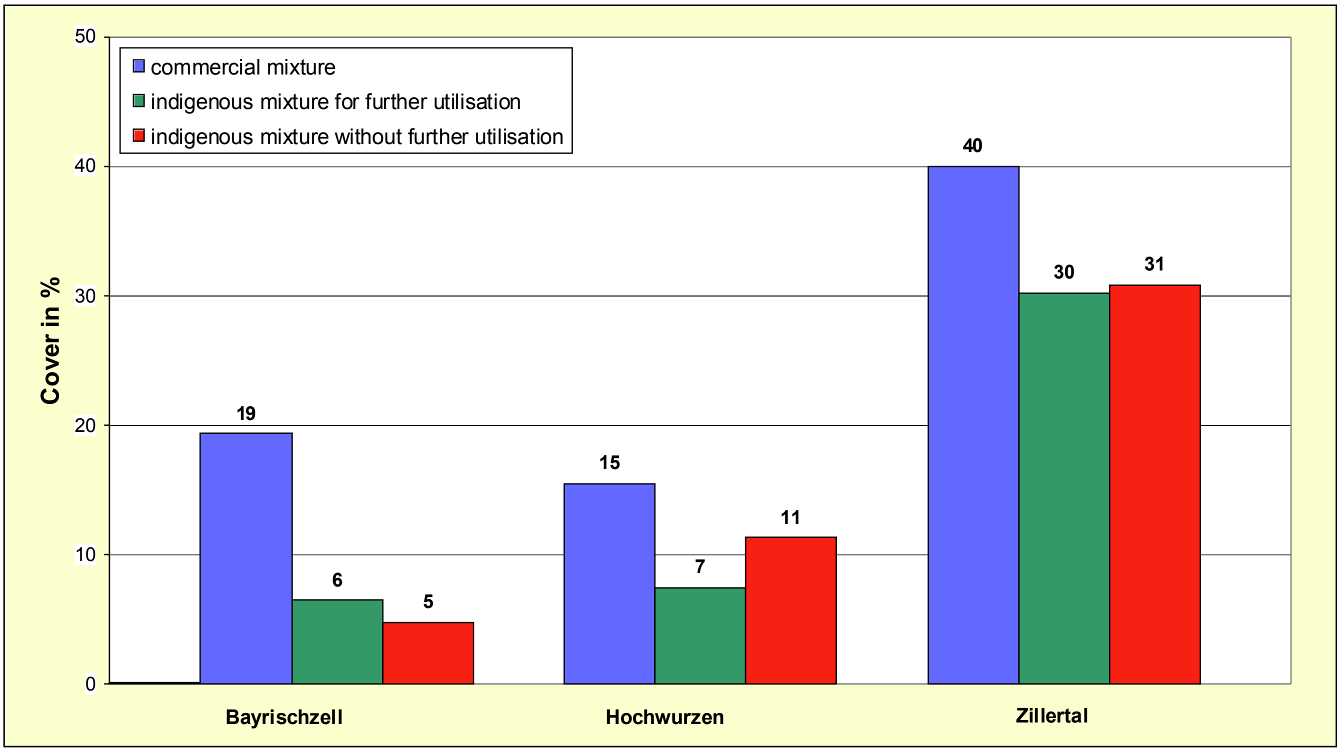

Figure 17: **Open soil in %, comparison of mixtures in 2002**

Table 16: **Absolute frequency of selected species, comparison of mixtures and sites in 2000 and 2001**

mixture 1	year	*Achillea millefolium*	*Agrostis capillaris*	*Festuca ovina*	*Festuca rubra*	*Lolium perenne*	*Lotus corniculatus*	*Phleum pratense*	*Poa pratensis*	*Trifolium hybridum*	*Trifolium repens*
Bayrischzell	2000	10,9	2,2	11,3	40,0	37,1	7,1	55,8	6,2	7,8	20,0
	2001	10,7	0,0	3,6	52,4	8,0	4,0	38,2	1,8	4,0	14,7
Piancavallo	2000	6,9	0,2	3,1	79,6	75,6	6,4	35,3	2,7	5,6	11,8
	2001	19,3	0,0	7,3	87,3	28,2	9,8	32,9	0,7	9,6	7,8
Hochwurzen	2000	4,2	0,9	0,0	26,4	21,0	7,2	14,1	0,2	15,0	8,4
	2001	10,9	0,2	0,0	58,4	24,7	32,2	6,0	0,4	40,9	6,4
Zillertal	2000	2,2	2,7	0,4	44,4	51,1	0,0	28,0	0,9	10,7	3,1
	2001	0,8	2,1	0,0	25,1	4,1	0,1	17,2	0,0	2,7	1,1
St. Anton	2000	9,3	0,0	0,0	45,3	40,3	4,0	73,3	0,0	9,7	1,0
	2001	13,0	0,0	1,1	42,7	1,1	0,9	71,1	1,3	10,7	1,1
total average	**2000**	**7,2**	**1,0**	**2,5**	**53,7**	**45,7**	**9,0**	**46,2**	**3,2**	**13,5**	**16,2**
	2001	**9,2**	**0,7**	**2,0**	**48,5**	**11,7**	**7,9**	**30,4**	**0,7**	**11,7**	**5,4**

mixture 2		*Achillea millefolium*	*Agrostis capillaris*	*Anthyllis vulneraria*	*Festuca nigrescens*	*Lolium perenne*	*Lotus corniculatus*	*Phleum alpinum*	*Poa alpina*	*Trifolium pratense*	*Trifolium repens*
Bayrischzell	2000	2,2	2,2	3,1	37,8	2,7	4,9	13,3	47,3	2,0	25,8
	2001	3,1	0,0	1,1	45,8	1,8	4,4	12,4	33,1	2,0	15,1
Piancavallo	2000	0,0	0,0	1,3	58,9	3,1	6,0	1,6	70,7	0,0	27,6
	2001	0,9	0,0	0,2	73,8	0,0	2,2	2,7	78,7	0,2	12,7
Hochwurzen	2000	5,9	2,8	4,0	29,3	9,4	0,6	0,9	0,8	18,2	0,0
	2001	18,9	1,1	18,2	55,8	11,3	1,1	0,0	7,1	0,0	0,7
Zillertal	2000	5,8	7,1	0,0	69,3	23,6	0,0	3,1	32,9	0,0	8,0
	2001	1,4	3,0	0,0	27,0	0,2	0,0	0,2	19,7	0,0	1,7
St. Anton	2000	24,3	0,0	0,3	67,3	7,3	0,7	10,7	39,3	3,7	0,3
	2001	20,8	0,0	0,0	58,1	0,0	0,2	0,0	79,4	4,1	0,0
total average	**2000**	**6,7**	**2,0**	**8,8**	**55,6**	**14,8**	**3,2**	**14,7**	**34,5**	**4,0**	**24,7**
	2001	**7,8**	**1,2**	**3,3**	**47,9**	**2,3**	**1,3**	**2,6**	**39,6**	**1,1**	**5,3**

mixture 3		*Achillea millefolium*	*Agrostis capillaris*	*Anthyllis vulneraria*	*Festuca nigrescens*	*Lolium perenne*	*Lotus corniculatus*	*Phleum alpinum*	*Poa alpina*	*Trifolium prat.* ssp. *nivale*	*Trifolium repens*
Bayrischzell	2000	0,7	0,2	4,0	36,0	4,9	4,4	14,0	45,3	1,6	31,1
	2001	4,4	0,0	0,4	44,4	1,3	3,3	11,8	28,7	0,7	9,3
Piancavallo	2000	33,8	0,0	51,3	75,3	2,2	6,4	0,0	66,0	0,0	0,4
	2001	50,4	0,0	30,7	80,4	1,6	4,9	0,0	67,1	0,4	0,7
Hochwurzen	2000	7,0	0,4	4,2	36,3	1,4	0,1	1,4	0,9	16,3	0,2
	2001	19,3	0,2	16,0	61,8	1,8	0,9	0,0	3,3	0,0	0,9
Zillertal	2000	7,1	6,2	0,0	78,7	19,6	0,0	0,4	37,8	0,0	12,0
	2001	1,9	2,4	0,0	28,8	0,3	0,1	0,2	18,9	0,0	2,6
St. Anton	2000	14,7	0,0	0,3	65,7	7,7	0,0	0,3	44,0	7,0	0,7
	2001	12,4	0,0	0,2	54,4	0,0	0,0	0,0	71,4	6,2	0,0
total average	**2000**	**15,7**	**1,2**	**18,6**	**61,9**	**8,4**	**1,8**	**11,4**	**32,6**	**4,2**	**18,6**
	2001	**15,1**	**0,9**	**7,9**	**49,8**	**0,9**	**1,6**	**2,0**	**34,7**	**1,2**	**2,7**

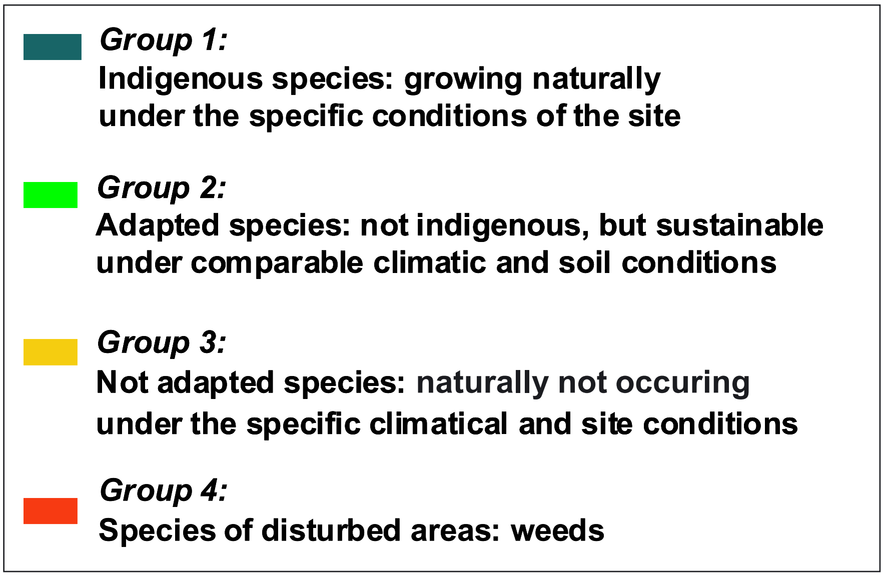

Figure 18: **Explanation of groups of species, referring to their ecological value**

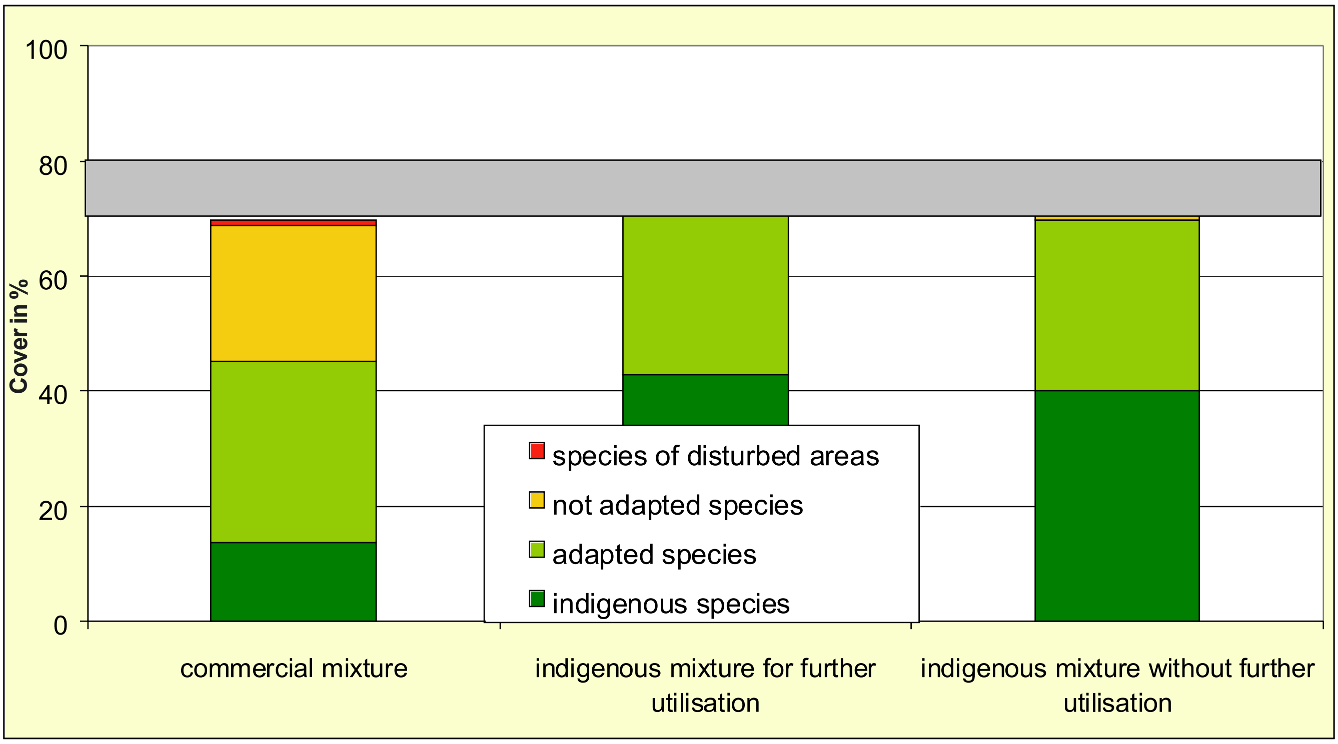

Figure 19: **Mean share of grouped species referring to their ecological value, all sites, 2002**

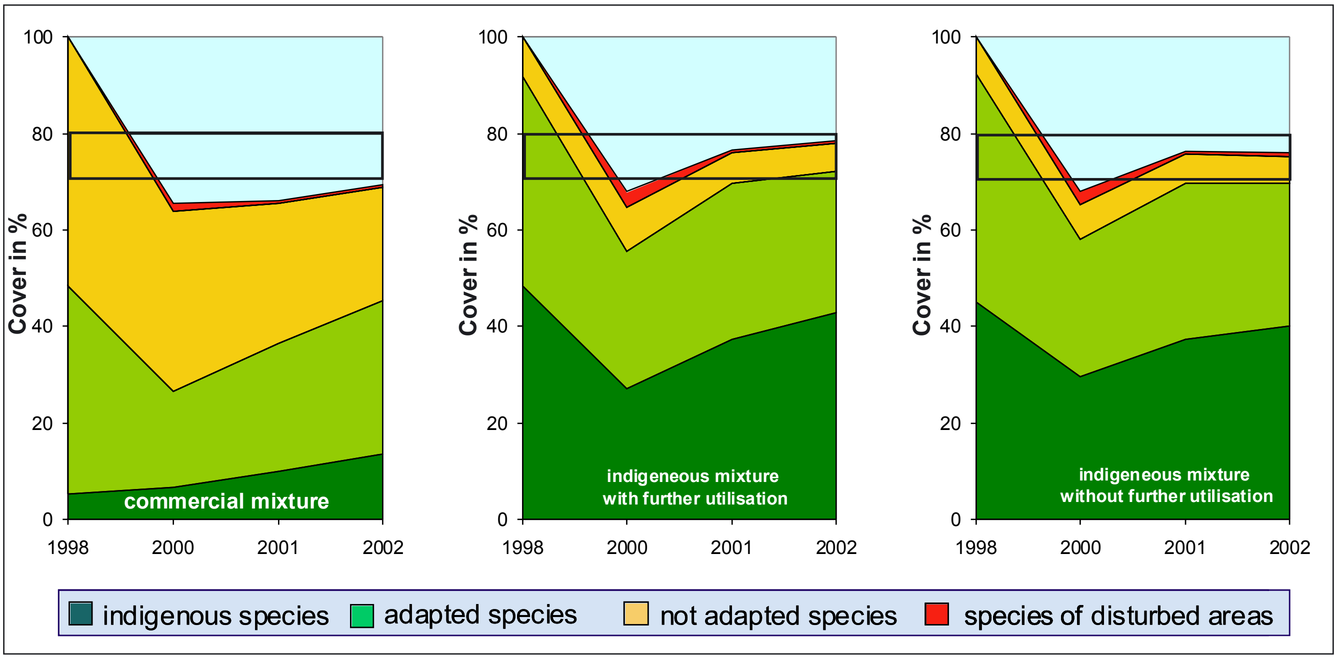

Figure 20: **Share of grouped species referring to their ecological value, all sites (1998 = % of weight in original seed mixture, 2000 - 2002 = species cover in %)**

location	**St. Anton**	**Zillertal**	**Hochwurzen**	**Piancavallo**	**Bayrischzell**
altitude	**2350**	**2280**	**1830**	**1435**	**1230**
Poa alpina	ripe seeds assessed	ripe seeds assessed	ripe seeds assessed	ripe seeds assessed	ripe seeds assessed
Festuca nigrescens	ripe seeds assessed	ripe seeds assessed	ripe seeds assessed	ripe seeds assessed	ripe seeds assessed
Phleum alpinum	no ripe seed assessed	ripe seeds assessed	ripe seeds assessed	ripe seeds assessed	ripe seeds assessed
Poa supina	ripe seeds assessed	no ripe seed assessed	ripe seeds assessed	ripe seeds assessed	ripe seeds assessed
Trifolium badium	ripe seeds assessed	ripe seeds assessed	ripe seeds assessed	ripe seeds assessed	ripe seeds assessed
Trifolium pratense* ssp. *nivale	ripe seeds assessed	ripe seeds assessed	ripe seeds assessed	ripe seeds assessed	ripe seeds assessed
Anthyllis vulneraria	no ripe seed assessed	no observation	ripe seeds assessed	ripe seeds assessed	ripe seeds assessed
Silene dioica	ripe seeds assessed	no observation	ripe seeds assessed	ripe seeds assessed	ripe seeds assessed
Agrostis capillaris	no ripe seed assessed	ripe seeds assessed	ripe seeds assessed	no observation	ripe seeds assessed
Phleum pratense	no ripe seed assessed	no ripe seed assessed	ripe seeds assessed	ripe seeds assessed	ripe seeds assessed
Lolium perenne	no ripe seed assessed	no ripe seed assessed	ripe seeds assessed	ripe seeds assessed	ripe seeds assessed
Trifolium hybridum	no ripe seed assessed	no ripe seed assessed	no ripe seed assessed	ripe seeds assessed	ripe seeds assessed
Trifolium repens	no ripe seed assessed	no ripe seed assessed	no ripe seed assessed	ripe seeds assessed	ripe seeds assessed

no ripe seed assessed ripe seeds assessed no observation

Figure 21: **Fertility of selected species at different sites**

Table 17: **Variance analysis of total number of species of sites Bayrischzell, Hochwurzen and Zillertal, 2002**

source		type III sum of square	df	mean square	F	significance
block	hypothesis	9,6	2	4,8	0,52	0,63
	error	36,9	4	9,2[b]		
mixture	hypothesis	218	2	109	11,8	0,02
	error	36,9	4	9,2[b]		
mixture * block	hypothesis	36,9	4	9,2	0,43	0,79
	error	1411	66	21,4[c]		
trial	hypothesis	15351	2	7675	359	0,00
	error	1411	66	21,4[c]		
mixture * trial	hypothesis	198	4	49,5	2,32	0,07
	error	1411	66	21,4[c]		

b: MS (trial * year * block) c: MS (error)

estimated marginal means

dependent variable: total number of species per plot

mixture	meansquare	standarderror	**trial**	meansquare	standarderror
commercial mixture	37,4	0,89	Bayrischzell	56,2	0,89
indigenous mixture for further utilisation	40,3	0,89	Hochwurzen	40,3	0,89
indigenous mixture without further utilisation	41,3	0,89	Zillertal	22,5	0,89

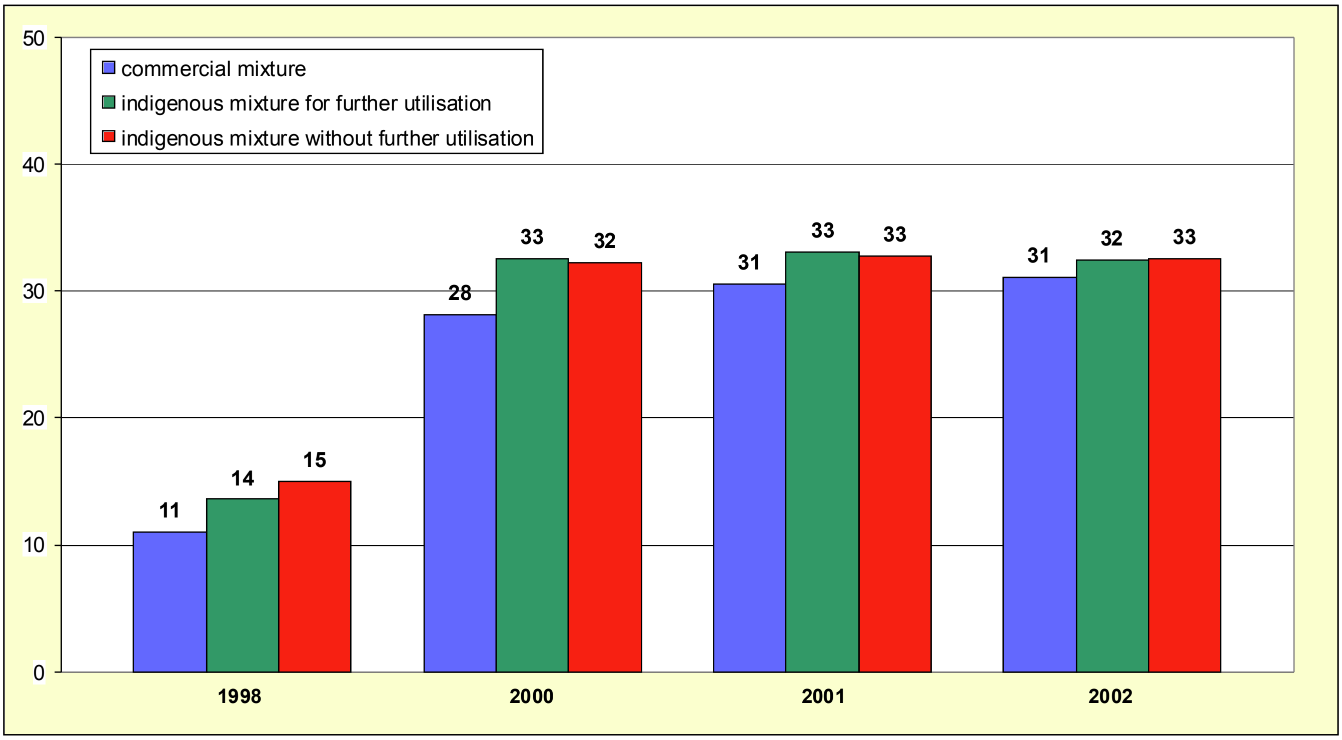

Figure 22: **Average of total number of species and all sites (1998 = number of species in seed mixture, 2000 - 2002 = number of species assessed)**

Table 18: **Root biomass in kg ha^{-1} from sites Bayrischzell and Hochwurzen 2002**

		hydroseed	mycorrhiza	covered top soil	total
Bayrischzell	commercial mixture	1135	1074	1159	1122
	indigenous mixture for further utilisation	1649	1213	904	1255
	indigenous mixture without further utilisation	1126	1184	1554	1288
	total	**1303**	**1157**	**1205**	**1222**
Hochwurzen	commercial mixture	1189	1205	918	1104
	indigenous mixture for further utilisation	1001	559	1253	937
	indigenous mixture without further utilisation	973	1206	1135	1105
	total	**1054**	**990**	**1102**	**1049**
total	commercial mixture	1162	1139	1038	1113
	indigenous mixture for further utilisation	1325	886	1078	1096
	indigenous mixture without further utilisation	1050	1195	1344	1196
	total	**1179**	**1073**	**1154**	**1135**

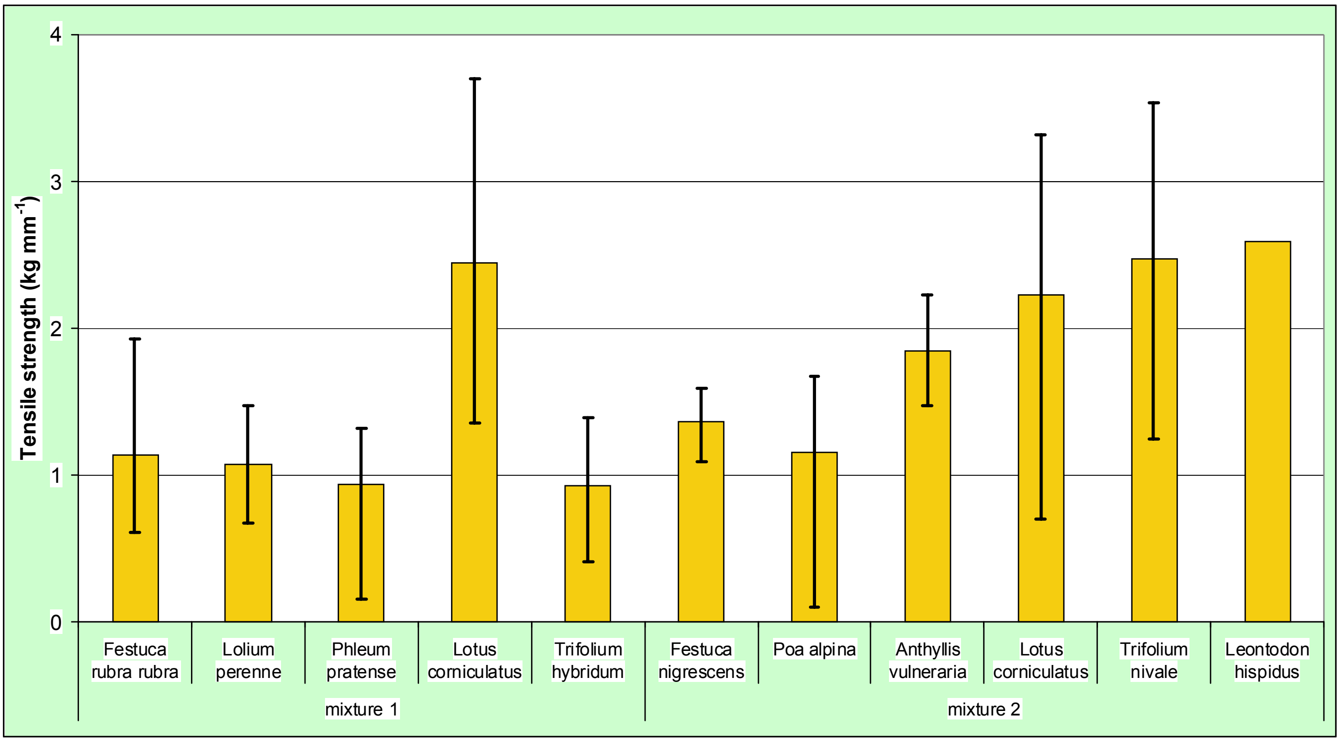

Figure 23: **Average, minimum and maximum tensile strength (in kg per mm diameter) of species, distance from the root bases 1,5 - 7,5 cm**

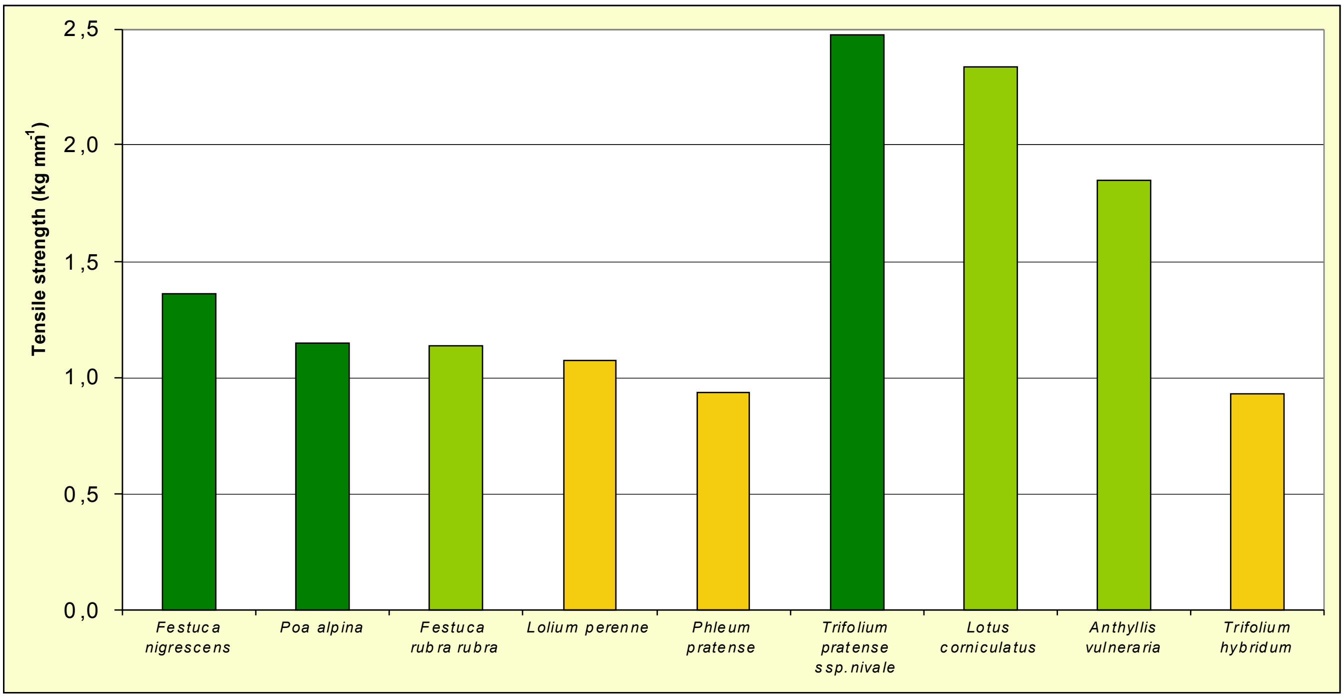

Figure 24: **Average tensile strength (in kg per mm diameter) of species grouped referring to their ecological value (distance from the root bases 1,5 - 7,5 cm)**

Table 19: **Average of growing height in cm in the year 2002**

	Bayrischzell	Hochwurzen	Zillertal	Piancavallo	St. Anton
commercial mixture	13,33	17,03	6,01	18,97	22,30
indigenous mixture with further utilisation	11,44	15,64	6,38	19,08	17,60
indigenous mixture without further utilisation	15,33	15,64	7,31	17,81	16,50

Table 20: **Dry biomass yield (kg ha^{-1}), comparison of sites and mixtures, (harvests 2000, 2001 and 2002)**

trailnumber	seed mixture	2000	2001	2002	average
Bayrischzell	commercial mixture	3053	2816	2611	2827
	indigenous mixture with further utilisation	2115	2872	2305	2431
Piancavallo	commercial mixture	722	857	1167	915
	indigenous mixture with further utilisation	528	586	1025	713
Val Zoldana	commercial mixture	1505	no harvest	no harvest	
	indigenous mixture with further utilisation	2915	no harvest	no harvest	
Hochwurzen	commercial mixture	564	1703	1936	1401
	indigenous mixture with further utilisation	954	3091	1939	1994
Zillertal	commercial mixture	no harvest	200	491	346
	indigenous mixture with further utilisation	no harvest	252	360	306
St. Anton	commercial mixture	no harvest	497	1389	943
	indigenous mixture with further utilisation	no harvest	789	1228	1008
total	commercial mixture	1461	1215	1519	1286
	indigenous mixture with further utilisation	1628	1518	1371	1290

Table 21: **Mean dry biomass (kg ha^{-1}) and significance of main effects (mixtures and techniques) and of their interaction calculated with variance analysis. Analysis of single years for each site**

		application technique				seed mixture			
		hydroseed	mycorrhiza	covered top soil	significance	commercial mixture	indigenous mixture with further utilisation	significance	mixture * technique
2000	Bayrischzell	3254	2565	1934	0,11	3053	2115	0,00	0,84
2000	Piancavallo	656	695	523	0,45	722	528	0,05	0,27
2000	Val Zoldana	2570	2350	1711	0,44	1505	2915	0,07	0,43
2000	Hochwurzen	760	140	415	0,00	327	551	0,10	0,17
2001	Bayrischzell	3025	2684	2822	0,80	2816	2872	0,87	0,99
2001	Piancavallo	682	884	598	0,49	857	586	0,14	0,25
2001	Hochwurzen	2550	1936	2705	0,20	1703	3091	0,01	0,37
2001	Zillertal	177	222	279	0,90	200	252	0,40	0,36
2001	St. Anton	572	502	855	0,06	497	789	0,01	0,58
2002	Bayrischzell	2559	2538	2278	0,71	2611	2305	0,20	0,69
2002	Piancavallo	1307	964	1017	0,64	1167	1025	0,41	0,44
2002	Hochwurzen	2296	1420	2096	0,15	1936	1939	0,99	0,27
2002	Zillertal	266	393	618	0,58	491	360	0,12	0,83
2002	St. Anton	1141	1612	1172	0,41	1389	1228	0,27	0,73

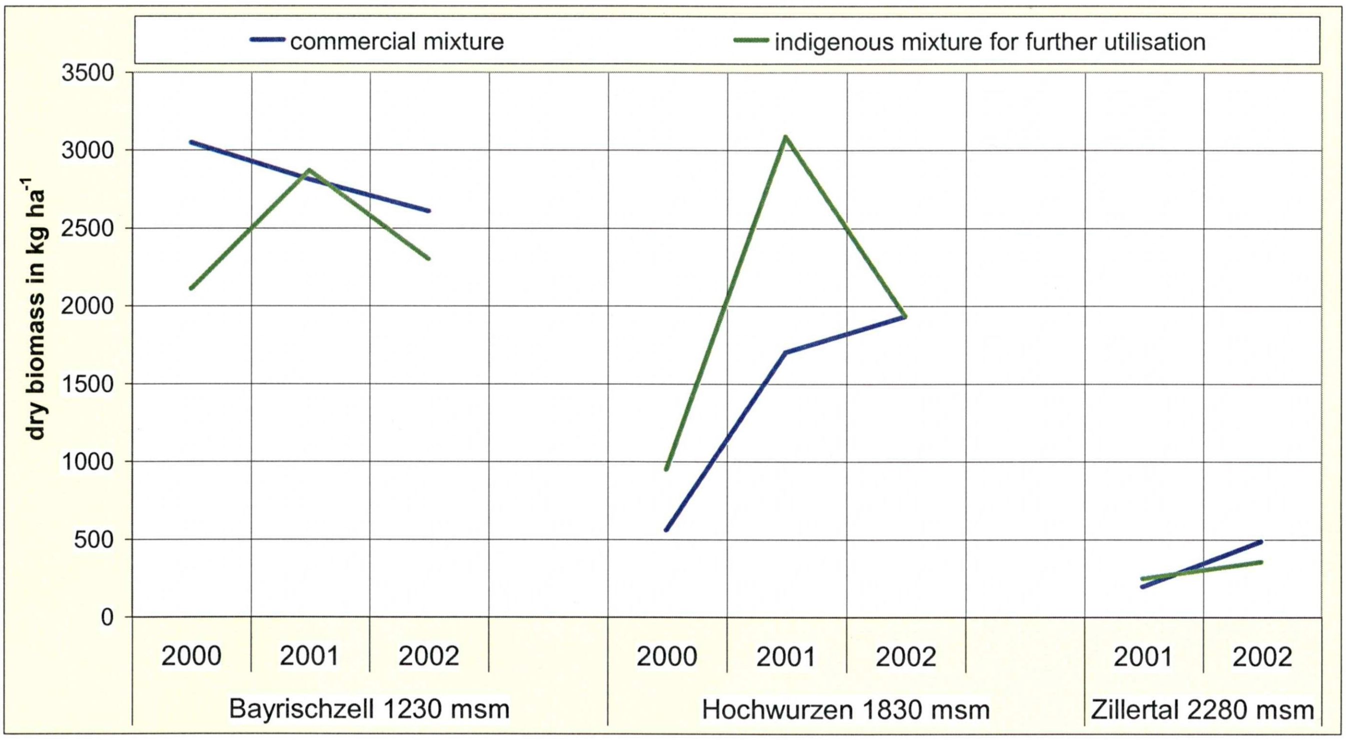

Figure 25: **Dry biomass yield in kg ha^{-1}, comparison of years and selected sites**

Table 22: **Digestibility and nutrition value of the sites Bayrischzell, Hochwurzen and Zillertal, comparison of mixtures and years**

		TS	NFE g/kg DM	XA g/kg DM asch	XF g/kg DM fibre	XL g/kg DM fat	XP g/kg DM protein	dO % DM digestibility	DO g/kg DM	ME MJ/kg DM	NEL MJ/kg DM
2000											
Hochwurzen	commercial mixture	202	544	93	223	19	122	67	606	9,15	5,31
	indigenous mixture with further utilisation	190	489	102	252	19	137	59	530	7,78	4,31
2001											
Bayrischzell	commercial mixture	279	533	71	249	19	128	71	663	10,18	6,07
	indigenous mixture with further utilisation	279	513	72	268	18	128	66	616	9,33	5,45
Hochwurzen	commercial mixture	191	492	79	255	23	152	61	561	8,34	4,72
	indigenous mixture with further utilisation	213	484	78	264	24	149	58	531	7,79	4,32
Zillertal	commercial mixture	442	377	63	702	19	95	46	428	6,53	3,86
	indigenous mixture with further utilisation	469	404	69	715	19	102	49	458	6,87	4,00
2002											
Bayrischzell	commercial mixture	260	530	86	237	22	125	67	611	9,24	5,38
	indigenous mixture with further utilisation	259	530	79	243	22	126	64	593	8,92	5,15
Hochwurzen	commercial mixture	173	391	76	251	23	141	58	537	7,91	4,41
	indigenous mixture with further utilisation	168	464	90	283	23	140	55	498	7,19	3,88
Zillertal	commercial mixture	326	573	62	249	18	98	71	662	10,16	6,06
	indigenous mixture with further utilisation	306	540	73	260	20	107	66	607	9,17	5,33
mean value											
Bayrischzell	commercial mixture	270	532	79	243	20	126	69	637	9,71	5,72
	indigenous mixture with further utilisation	269	522	75	255	20	127	65	605	9,12	5,30
Hochwurzen	commercial mixture	189	476	82	242	21	138	62	568	8,46	4,81
	indigenous mixture with further utilisation	190	479	90	266	22	142	57	520	7,59	4,17
Zillertal	commercial mixture	384	475	62	430	18	97	58	545	8,35	4,96
	indigenous mixture with further utilisation	388	472	71	474	20	105	57	533	8,02	4,66

Table 23: **Machine, labour, additional and total costs in Euro/ha/year relevant for Austria**

Species	Machine costs	Labour costs	Additional costs	Total costs
Festuca supina	236	43	348	627
Festuca pseudodura	236	43	345	624
Poa violacea	219	96	413	728
Phleum alpinum	219	96	413	728
Phleum hirsutum	219	96	400	716
Deschampsia cesp.	219	96	376	692
Avenella flexuosa	219	96	414	729
Sesleria albicans	219	96	484	799
Trifolium alpinum	244	47	418	709
Trifolium nivale	244	47	404	695
Trifolium badium	211	43	546	800
Anthylis vulneraria	211	43	490	743
Anthylis alpestris	211	43	516	770
Leontodon hispidus	325	54	664	1.042
Winter wheat	584	127	333	1.044
Summer barley	469	104	258	828

Table 24: **Average as well as minimum and maximum differences in profit (Euro) per ha year^{-1}between winter wheat and indigenous seed production relevant for Austria**

Species	Average difference in Euro/ha/year	Minimum/Maximum
Festuca supina	872	-17 / 2.130
Festuca pseudodura	874	-201 / 1.249
Poa violacea	1.094	-187 / 4.155
Phleum alpinum	927	-632 / 2.263
Phleum hirsutum	216	-619 / 1.162
Deschampsia cespitosa	74	-484 / 854
Avenella flexuosa	1.344	-592 / 2.444
Sesleria albicans	174	-596 / 1.714
Trifolium alpinum	-475	-775 / 25
Trifolium nivale	1.071	-595 / 1.238
Trifolium badium	220	-515 / 370
Anthylis vulneraria	2.727	727 / 4.227
Anthylis alpestris	1.075	200 / 3.825
Leontodon hispidus	1.537	667 / 4.147

Table 25: **Material per m², hours per ha and price per unit for application techniques T1 to T4**

Material	Costs	T1	T2	T3	T4
	Euro/kg	Amount of material (g m^{-2})			
Cellulose	0,6100	80			80
Straw	0,1321			500	
Three dimensional mat	7,7760				500
Bitumen	0,7000			40	
Organic carrier	2,1802		65	65	
Gluten	3,0523	15			15
Organic gluten	5,8100		3,5	3,5	
Mycorrhiza	4,3600		65	65	
Mineral fertiliser	0,2375	20			20
Dry compost	0,1941		80	80	
Cover seed (rye)	0,5087				15
Commercial seed mixture	3,5600	20	20	20	20
Indigenous seed mixture	18,1600	12	12	12	12
	Euro/nail	Number of nails m^{-2}			
Nails	0,3050				15
	Euro/hour	Hours per ha			
Sprayer	145,00	6,0	6,0	12,0	6,0
Blower	25,00			7,5	
Muli	60,00	0,5	0,5	3,0	1,5
Truck	50,00	1,0	1,0	1,0	1,0
Labour	20,00	12,0	12,0	33,0	77,0

Table 26: **Material (without seeds), machine, labour, total costs in Euro/ha for T1 to T4**

	T1	**T2**	**T3**	**T4**
Material costs	993	4.610	5.550	44.525
Machine costs	950	950	2.158	1.010
Labour costs	240	240	660	1.540
Sum	***2.183***	***5.800***	***8.368***	***47.075***

Table 27: **Costs for seed mixtures, utilisation, revenue from cutting/grazing in Euro/ha and risk factors for T1 to T4**

	T1	T2	T3	T4
Costs for seed mixture (commercial/indigenous)			712/2.180	
Costs for utilisation (cutting/grazing)			760/30	
Revenue commercial	942	844	910	910
Revenue indigenous	948	699	926	926

Table 28: **Bio mass and quality in MJ NEL per ha and year and milk producing potential in kg fat corrected milk (FCM)/ha restored area**

	Commercial seed mixture		Indigenous seed mixture	
	MJ NEL ha^{-1}	Kg FCM ha^{-1}	MJ NEL ha^{-1}	Kg FCM ha^{-1}
Technique 1	8.617	2.693	8.670	2.709
Technique 2	7.719	2.412	6.393	1.998
Technique 3 + 4	8.318	2.599	8.464	2.645