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Soil Erosion and Surface Runoff on Slopes in Mountain Environment Depending on Application Technique and Seed Mixture – A Case-Study

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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, tourists infrastructure and roads (CIPRA 1998). 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.

High altitudes as the most sensible part of the Alps can be defined as areas within the pre-alpine and alpine belt i.e. areas above 1,600 msm in the Eastern Alps and areas above 1,800 msm in the Central Alps (Krautzer et al. 2006). Every disturbance in such alpine ecosystems leads to interference that requires different technical and ecological measurements. For lack of plant material in most cases, seed mixtures containing grasses and clover are normally used to establish vegetation again. Restoration of damaged areas in high altitudes is much too often done with an inadequate combination of technical and biological measurements. Cheap application techniques and cheap seed mixtures from species that are not adapted for high altitudes are state of the art. The resulting ecological and economical damage is considerable: soil erosion, extreme surface runoff, degradation of the vegetation, frequent reseeding, 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.

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 dealing with the thematic to restore damaged areas using a combination of improved application techniques combined with seed mixtures of indigenous species. The goal of this project was to create a new state of the art in ecological restoration of damaged areas in high altitudes of the Alps. Results obtained during the four years 1999 to 2002 at 8 different locations in altitudes between 1,200 and 2,300 metres clearly showed multiple positive effects if indigenous sub-alpine and alpine species are used for restoration. Up to 20 %

higher vegetation cover and thus better protection against erosion three years after sowing, no need for further fertilisation and maintenance on most sites and a much higher percentage of sustainable species are only some of the essential advantages (Krautzer et al. 2010). However, the most risky period where erosion processes can cause considerable damage are the weeks after sowing. Especially indigenous species are germinating and growing very slow. Depending on altitude, vegetation needs 8 to 12 weeks to reach a vegetation cover that is able to reduce erosion to an acceptable degree (Stocking & Elwell 1976, Mosimann 1984). During this period, the vegetation 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 made in order to get knowledge about the influence of different soils and vegetation on erosion and surface runoff in high altitudes (Czell 1972, Schaffhauser 1982, Bunza 1989, Markart et al. 1997). But up to now only little data is available, describing the relations between precipitation, surface runoff and soil erosion during the period after restoration of alpine locations, what is strongly influenced by the chosen application technique (Florineth 2000). On the other hand, restoration companies assure that cheap application methods like normal hand sowing combined with cover crops or plain hydroseeding can be used in most cases (Neuschmid 1996).Up to now we 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 the course of the EC project “Alperos”, the Agricultural Research and Education Centre Raumberg-Gumpenstein tried to acquire special information about the effects of different common and improved application techniques on surface runoff and soil losses as a basis for further recommendations or stipulations. A special erosion facility was built up in order to measure erosion in dependency on different application techniques after restoration in high altitudes. Three different trials were carried out in order to answer the following main questions: Water flow and soil losses depending on precipitation, influence of seed mixtures on soil erosion, effect of cover grass and cover crop in comparison to hydroseeding and additional protection of soil surface.

2. Material and methods

2.1 Site conditions

The trial were carried out at the location Hochwurzen (1,830 m), a part of the famous skiing centre of Schladming, Austria (13.64° E, 47.36° N). The erosion facility with the plots were set up directly on a ski run with an average inclination of 38 % and an exposition of southeast (SE). The parent rock is Gneis, soil type Leptosol. The soil depth was measured with an average of 16 cm, the water regime can be described as fresh. The climax plant community around the experimental trial on the location Hochwurzen is the Larici-Piceetum; the antropogenic vegetation belongs to the Sieversio-Nardetum strictae. The soils are acid dystric cambisols and leptosols in the Al buffer range (Nestroy et al. 2000).

The classification and descriptions of the soil conditions were done according to the official Austrian guidelines for fertilization of grassland (BMLFUW 2006). The chemical soil conditions of the machine graded site were characterised by a slightly acidic soil pH (carbonate buffer range); relative high humus content (dry combustion) and a relative small C/N ratio (Table 1). The chemical analyses showed a low value of Calcium-Acetat-Lactat (CAL)-extract soluble P; a sufficient amount of Calcium-Acetat-Lactat (CAL)-extract soluble

K; a favourable base saturation of Ca and Mg and low K saturation. The soil contained a sufficient content of EDTA extractable Fe, Mn, Cu and Zn (BMLFUW 2006).

pH ($CaCl_2$)	6.6	P (CAL-extract mg kg^{-1} at pH > 6)	13.0
Humus %	4.0	K (CAL-extract mg kg^{-1})	47.5
N tot (%)	0.2	$CaCO_3$ %	2.2
Mg ($BaCl_2$-extract mval $100g^{-1}$)	2.3	K ($BaCl_2$-extract mval $100g^{-1}$)	0.1
Ca ($BaCl_2$-extract mval $100g^{-1}$)	9.2	Na ($BaCl_2$-extract mval $100g^{-1}$)	0.1
Fe (EDTA-extract mg kg^{-1})	260.7	Cu (EDTA-extract mg kg^{-1})	9.3
Mn (EDTA-extract mg kg^{-1})	86.0	Zn (EDTA-extract mg kg^{-1})	4.0

Table 1. Soil parameters of site “Hochwurzen”

The average yearly temperature of the site lies at 3.5° centigrade, precipitation at about 1200 mm per year. A meteorological station was installed about 60 m faraway from the experimental plots. Rainfall was measured every 10 seconds and an hourly average was calculated and stored on the data logger. On site Hochwurzen, snow melt ended during the last third of May.

2.2 Description of the erosion facility

In order to measure the effects of different techniques on erosion, a mobile erosion facility with three chambers was set up. Figure 1 shows a sketch of the erosion facility. The surface runoff and soil losses from 3 different plots (40 m² each) were collected at the bottom of the plots and passed through a tube to 3 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 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 was not available.

2.3 Description of the trials

In general, our available equipment restricted us to three chambers per year. Therefore, no replications and no statistic 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 an herbicide with the active substance Glyphosate. In spring 2000 and 2001, the first 5 cm of soil surface were removed and stored soil surface from a depot near the trial was applied. Table 2 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).

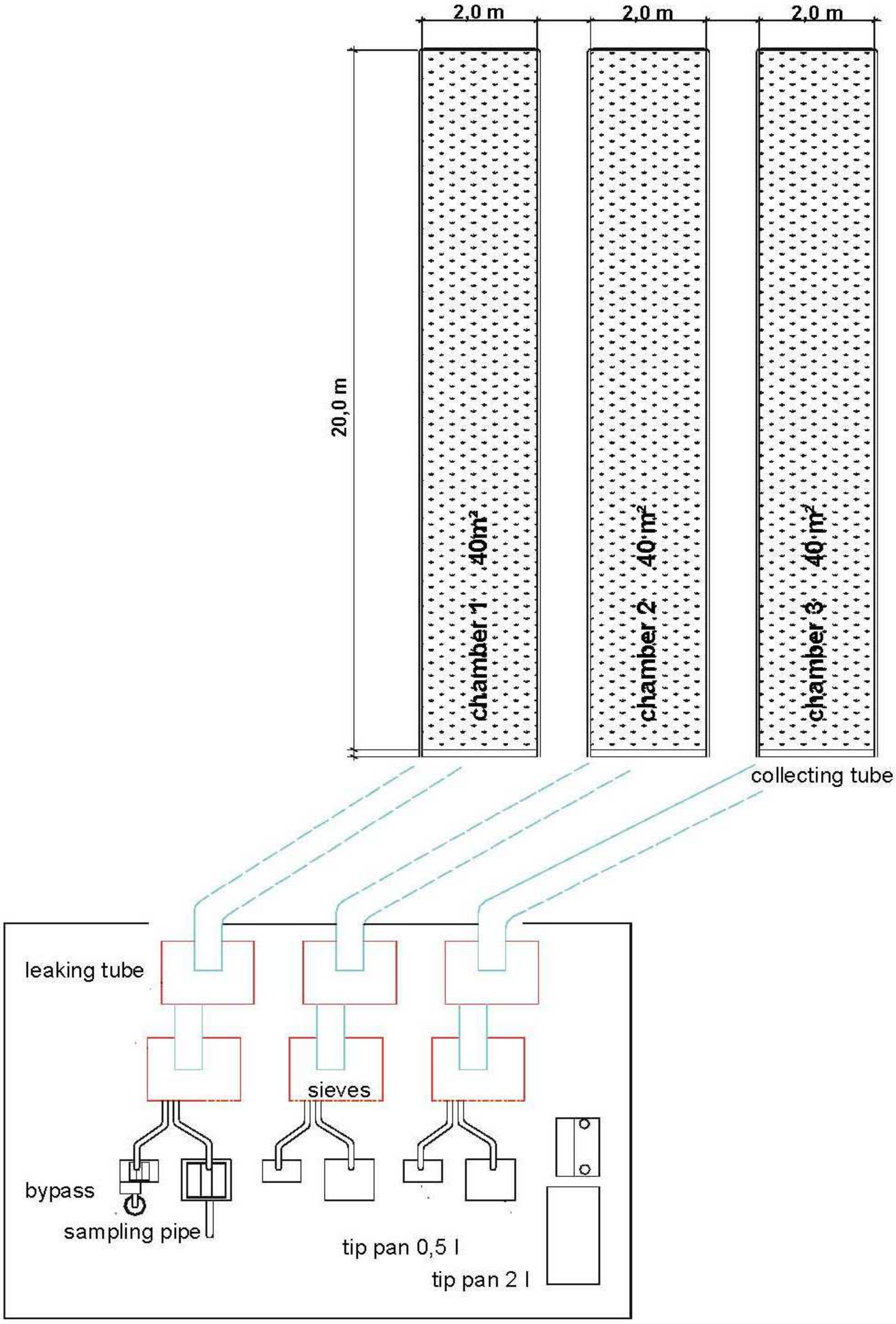

Fig. 1. Sketch of erosion facility “Hochwurzen”

Photo 1. Tip pans of 0.5 and 2 litres of the erosion facility "Hochwurzen"

Photo 2. The collecting tube at the bottom of the plots

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

Table 2. Overview of the different trials (application techniques) from 1999 to 2002 on the erosion facility

In 1999, a pilot trial with 3 plots was set up in order to compare a seed mixture of commercial lowland species with an indigenous seed mixture of alpine species (Table 3). 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. 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 soil surface on surface runoff and soil losses. During the investigation period of 1999, a precipitation of 350 mm was registered by our climatic station.

commercial mixture		% of weight	indigenous seed mixture	% of weight
grasses				
	Agrostis capillaris	4.60	*Agrostis capillaris*	4.00
	Festuca ovina	2.50	*Festuca nigrescens*	35.00
	Festuca rubra	31.00	*Festuca violacea*	5.00
	Lolium perenne	15.70	*Lolium perenne*	3.00
	Phleum pratense	19.90	*Phleum alpinum*	10.00
	Poa pratensis	10.60	*Poa alpina*	15.00
			Poa supina	5.00
leguminosae				
	Lotus corniculatus	5.00	*Anthyllis vulneraria*	5.00
	Trifolium hybridum	2.40	*Lotus corniculatus*	3.00
	Trifolium repens	4.20	*Trifolium badium*	5.00
	Vicia sativa	3.40	*Trifolium nivale*	3.50
herbs				
	Achillea millefolium	0.70	*Achillea millefolium*	1.00
			Dianthus superbus	0.50
			Leontodon hispidus	1.00
			Silene vulgaris	0.50

Table 3. Composition of commercial and indigenous seed mixture

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 restored areas with an inclination of more than 30 % from erosion. 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 loss 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.

Photo 3. The setup of the three chambers of the trial

From 2000 to 2001, a third trial was set up in order to assess the efficiency of an additional protection of soil surface (chamber 3) in comparison to the common used techniques hand sowing plus cover crop oat (70 kg ha^{-1}, chamber 1) and hydroseeding (chamber 2). The hydroseeding contained cellulose (80 g m^{-2}) and gluten ("Curasol", 15 g m^{-2}). For all chambers we used organic fertiliser "Biosol" (200 g m^{-2}) and indigenous seeds (15 g m^{-2}). On chamber 3, again the straw net "Greenfield S 100" (350 g m^{-2}) was applied on the soil surface. 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 corresponding vegetation cover of the three chambers was measured 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.

Photo 4. The experimental trial after the application of the different techniques

3. Results

In 1999 we managed the set up 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 soil surface. In order to avoid interactions with application techniques, we used normal hand sowing. During the investigation period, 2 heavy raining events with a precipitation of more than 15 mm h^{-1} took place. Figure 2 shows the summarized 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 to the soil. In comparison, the additional cover of soil surface was able to reduce surface runoff to 1 % of corresponding precipitation. A similar relation was observed with soil losses. On the two chambers with hand sown seed mixtures soil losses from 640 kg ha^{-1} (commercial mixture) up to 780 kg ha^{-1} (indigenous seed mixture) were measured. The straw mat was able to reduce soil losses to 26 kg ha^{-1}, an amount of 4 % compared to chamber 1.

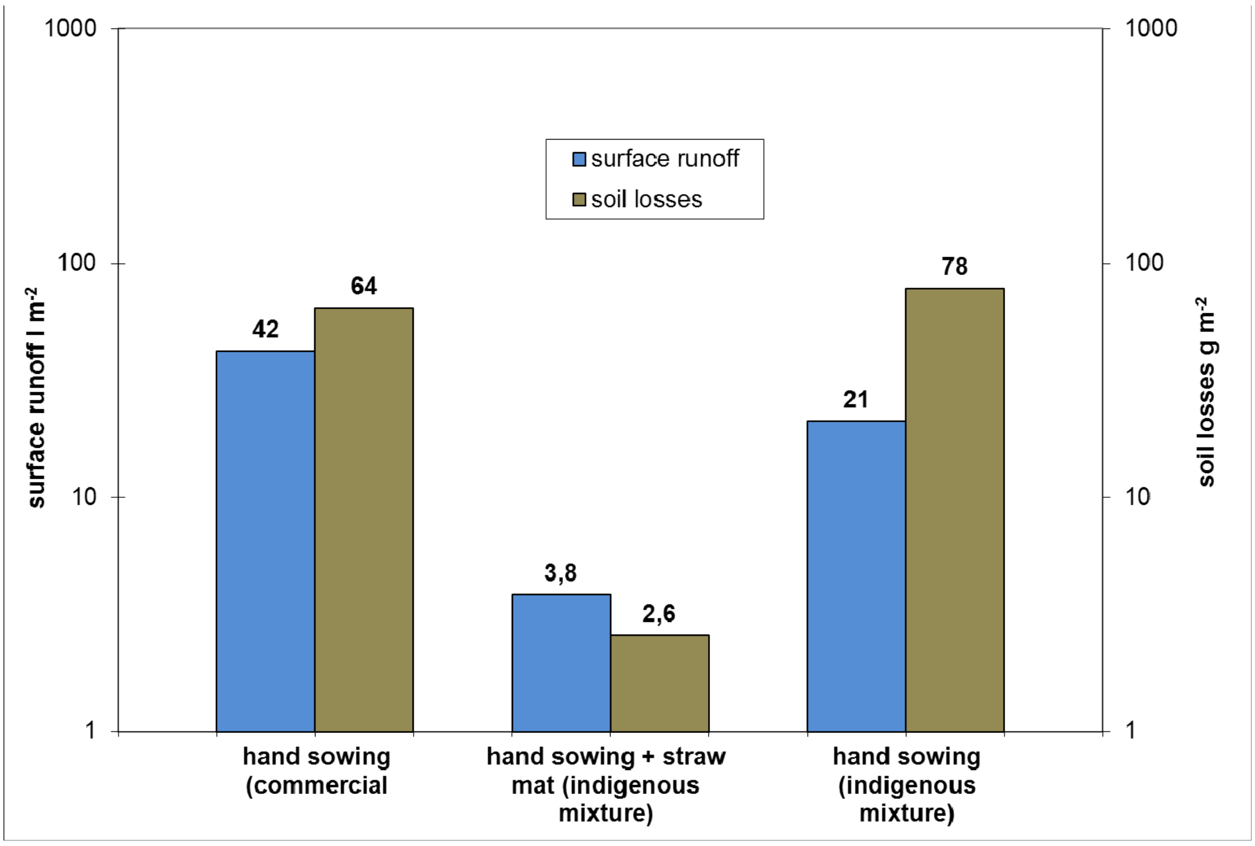

Fig. 2. Soil losses and surface runoff depending on precipitation (362 mm), observation period from 02-08-99 to 02-09-99

In the last week of June 2000, the second trial started. This year the investigation period lasted for 18 weeks with a precipitation of 810 mm. During the investigation period, 3 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 rye of the old landrace "Tyrolean summer rye". As nursery grass, we chose *Lolium perenne* of the variety "Guru", a variety with very good winter hardiness. Corresponding to the extended investigation period, total surface runoff and soil losses were higher in comparison to the year before. Surface runoff of normal hand sowing reached 9.6 % of precipitation, 2 % less than the year before (Figure 3). 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 reached nearby 2.8 t ha^{-1}. Again, a bit lower values were measured for 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 help of fast growing but short living components of the seed mixtures was not substantial. The available 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 of single samples were very high. Therefore, no exact interpretation of results was possible. In a general view, nutrient losses were below 0.5 kg ha^{-1} for P and from 1 to 1.5 kg ha^{-1} for K, corresponding to the poor nutrient content of the soil (Table 1). A comparison of the amounts of losses of N, P, K and Mg between the single trials approximately reflected their different stability against erosion.

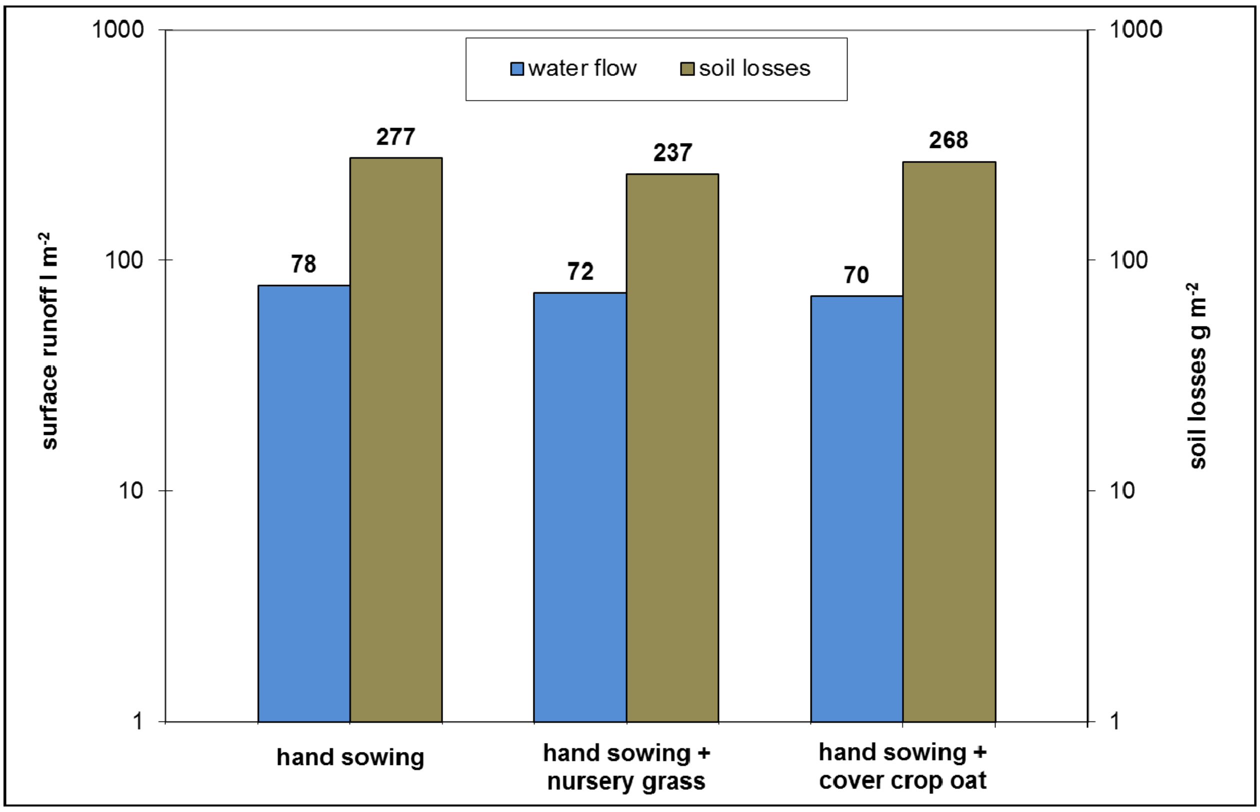

Fig. 3. Soil losses and surface runoff depending on precipitation (810 mm), observation period from 21-06-00 to 25-10-00

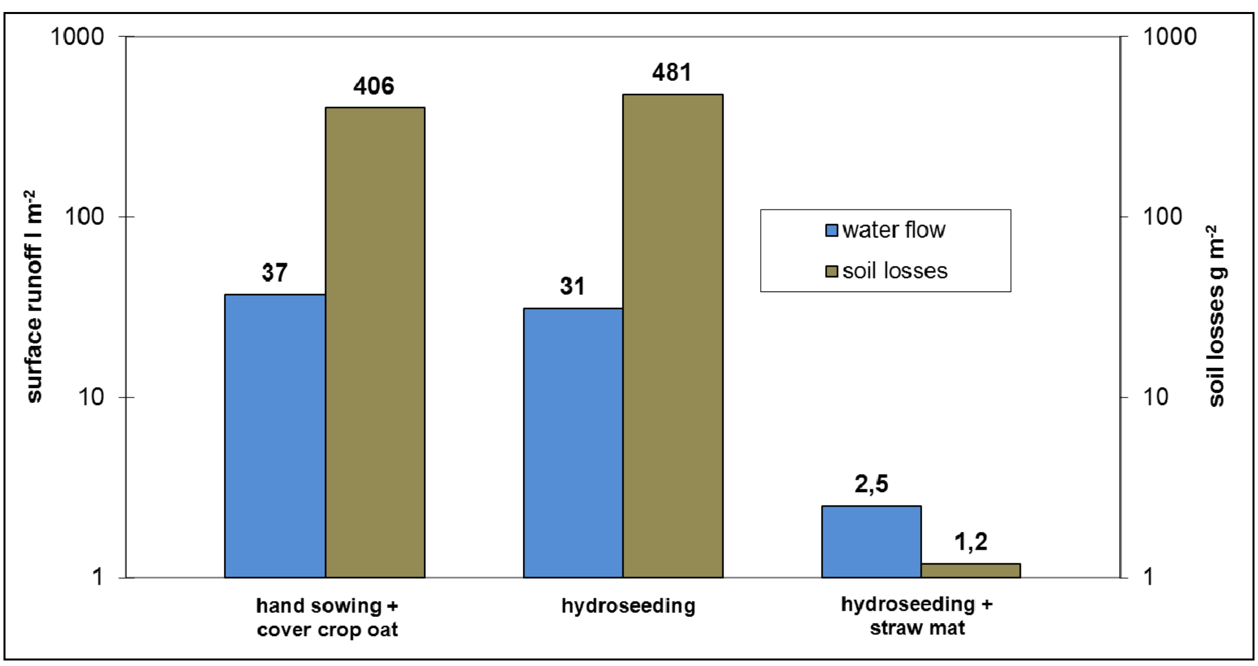

Fig. 4. Soil losses and surface runoff depending on precipitation (568 mm), observation period from 27-06-01 to 11-10-01

The third trial was set up at the end of June 2001. It was decided to run the erosion facility up to the end of vegetation period 2002 in order to get information about erosion processes the year after restoration. The first period lasted for 15 weeks with a precipitation of 568 mm and 1 heavy raining event. The equipment worked without technical problems. With this final trial we compared the technique hand sowing plus cover crop (this year oat, also a very common cover crop for restoration) to the world wide most used technique hydroseeding. As third technique, we chose hydroseeding with an additional cover of soil surface by the straw mat in order to measure the influence of protection by organic material a second time. Surface runoff from chamber 1 (hand sowing) reached 6.5 % of corresponding precipitation (Figure 4). For application technique hydroseeding, 5.5 % were measured. Again, the additional protection of soil surface led to a clear reduction of surface runoff, this time below 0.5 %. 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 was washed out below the straw net.
Figure 5 shows the connection between precipitation and surface runoff depending on application technique during a raining event that took place on 10th August 2001, described as hourly sum total. From 9:00 to 24:00, a precipitation of 47 mm was measured.

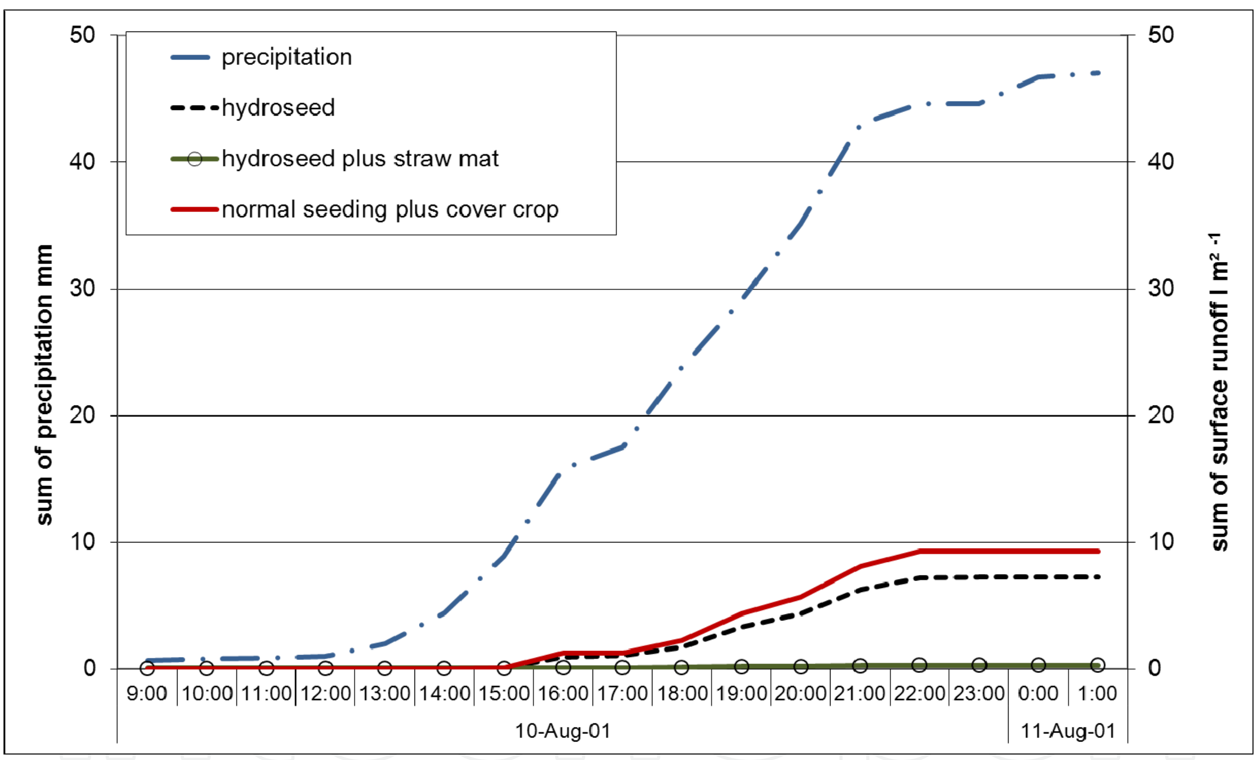

Fig. 5. Sum of precipitation and surface runoff in comparison of different application techniques during a raining event (Krautzer & Klug 2009).

The sum up of surface runoff for chamber one reached 15.8 % of precipitation, for chamber two 12.3 % and for chamber three only 1.8 %. This example showed that during periods with heavy raining events the proportion of surface runoff and therefore soil losses increases, compared to average precipitation. Figure 6 shows the same correlation between precipitation and surface runoff depending on application technique described as hourly mean values. With this figure 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 precipitation and absorbability of the soil.

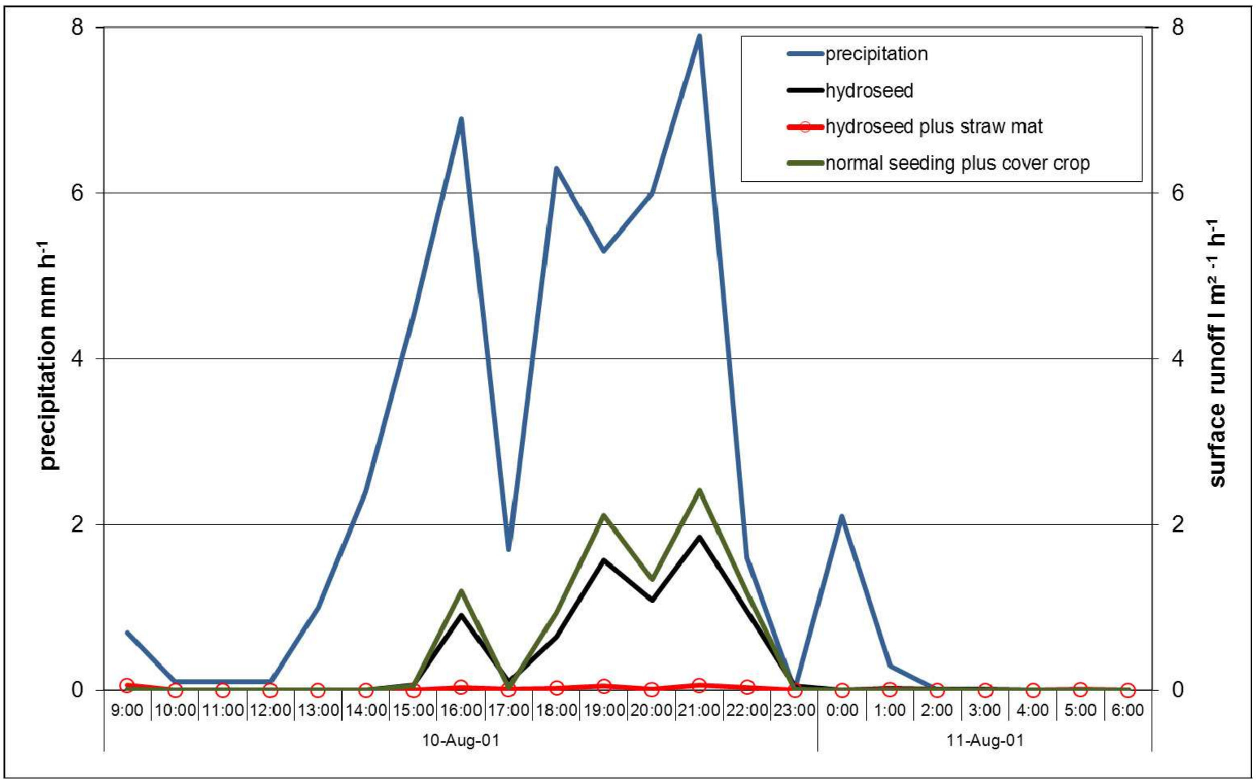

Fig. 6. Hourly values of precipitation and surface runoff in comparison of different application techniques during a raining event

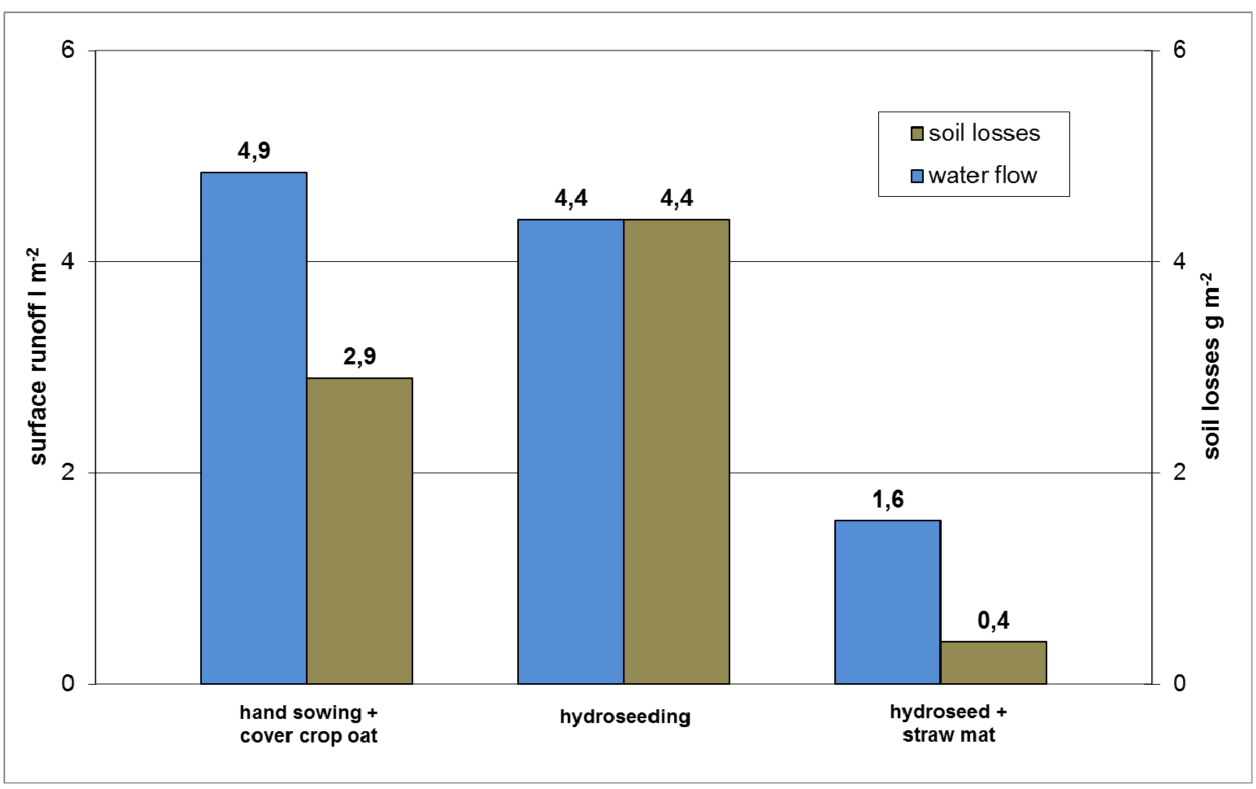

Fig. 7. Soil losses and surface runoff depending on precipitation (1,066 mm), observation period from 23-05-02 to 28-08-02

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, 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 7).

Photo 5. Vegetation cover on the plot with the technique hand sowing plus cover crop a year after setup (2002), the fine-grained material was washed out

Again, for the techniques hand sowing and hydroseeding the highest water flow was measured, but in relation to total precipitation only 0.5 % respectively 0.4 % of total precipitation. The soil losses for both techniques were between 29 and 44 kg ha^{-1}, an amount that is neglectable. However, again the technique with straw mat performed much better in comparison, with surface runoff of less than 0.2 % of total precipitation and soil losses of 4 kg ha^{-1}.

Water flow and soil losses are not only a result from total precipitation. Both the intensity of the raining event and the kinetic energy from the raindrops reaching the soil surface are responsible for erosion. Therefore, a direct comparison of all assessed application techniques between years is not possible. However, Figure 8 gives a general view of surface runoff caused by all compared application techniques 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 from 28-58 l m^{-2} was measured. Only the additional protection of soil surface was able to cause a clear reduction to a surface runoff from 2-5 l m^{-2}.

Photo 6. Vegetation cover on the plot with the technique Hydroseed a year after setup (2002), the fine-grained material was washed out

Photo 7. Vegetation cover on the plot with the technique Hydroseed with straw mat a year after setup (2002), no soil losses was visible

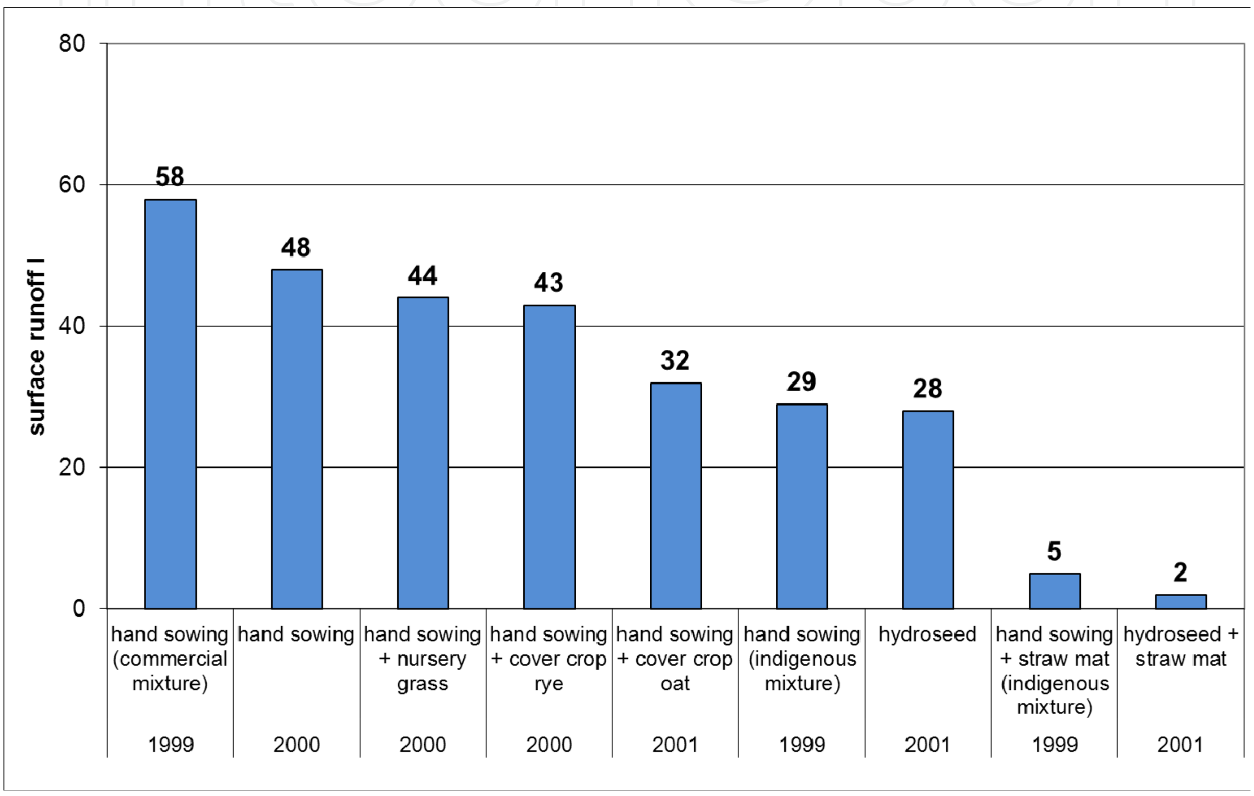

Fig. 8. Surface runoff referring to 500 mm precipitation, comparison of all sites (1999-2001)

A comparable proportion between soil losses and application techniques referring to 500 mm precipitation is visible in Figure 9. Corresponding to 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}.

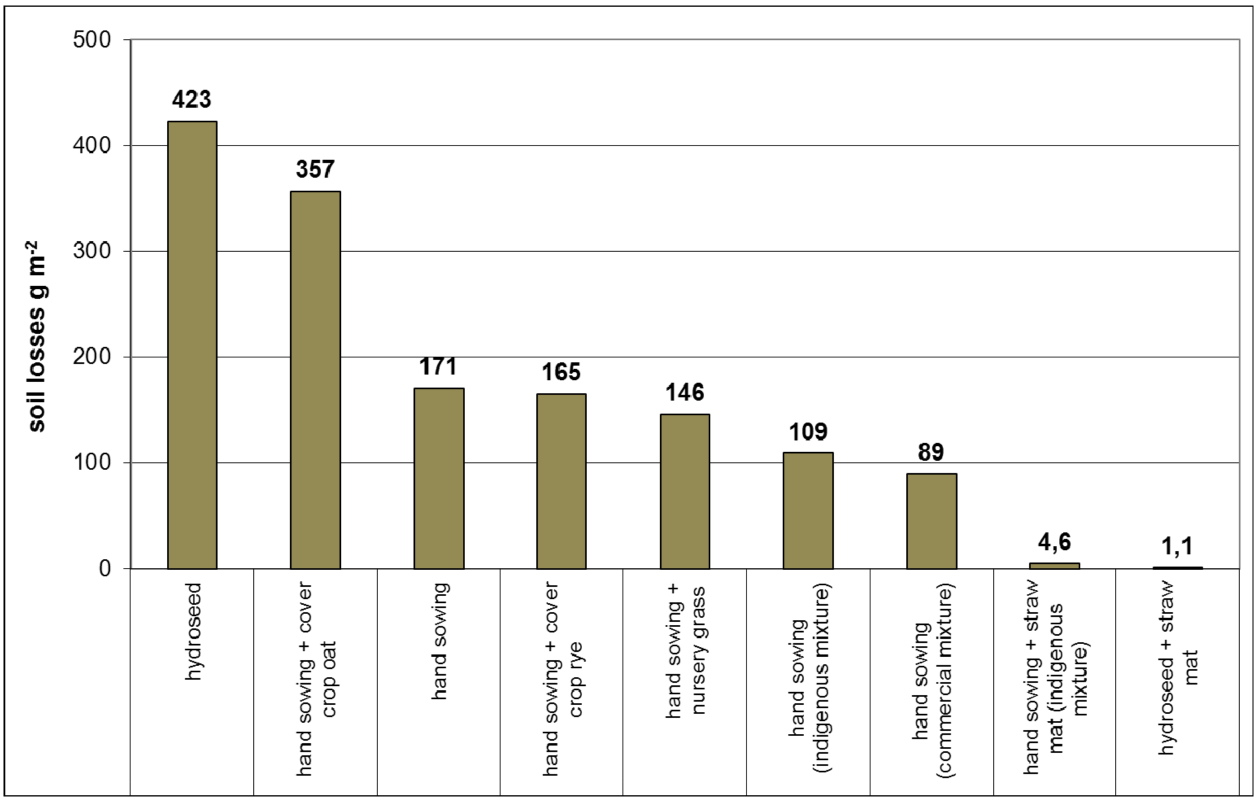

Fig. 9. Soil losses referring to 500 mm precipitation, comparison of all sites (1999-2001)

4. Discussion

The goal behind all restoration activities following interventions 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 harmlessly. If rain drops reach the ground unimpeded, the kinetic energy damages the soil aggregates. This also reduces the water receptivity of the soil. Water not infiltrated the soil is running down the slope, causing erosion. A higher surface runoff is not definitely associated with higher soil erosion. Not only the amount of surface runoff but also other factors (type and coverage of vegetation, soil conditions) determine the extent of soil erosion (Stocking & Elwell 1976). Mosimann (1984) calculated a clear connection between vegetation cover and intensity of erosion. Up to altitudes of 1,600 m a minimum of 70 % vegetation cover is required to avoid erosion. Above timberline, more dense vegetation with a cover of about 80 % is recommended. Results of our EU-project Alperos clearly showed multiple positive ecological effects up from the 2nd year after sowing, if indigenous species were used. To reach sustainable vegetation with a cover exceeding the minimum requirement of 80 %, the use of indigenous seed mixtures is a precondition (Krautzer & Wittmann 2006).
The best period for restoration activities in high altitudes would be the first 4 weeks after snow melt (Lichtenegger 1994). During this period, most soils have a satisfying water content, also on exposed sites. In alpine environments, vegetation has 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 & Schütz 1986). Our assessment on vegetation cover of the plots showed, that under average conditions of high altitudes this minimum cover can be reached the second vegetation period at the earliest. This requires application techniques with additional protection of soil surface for the first vegetation period. From an economic point of view, restoration companies will always try to reach minimum requirements with a minimum of costs. Therefore it is important to give clear answers 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 correlations are discussed.

With our 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 the weeks after sowing was expected for indigenous seed mixtures. However, the harsh conditions in 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 neutralizing their greater productivity (Jones et al. 1989) Therefore, results obtained during the investigation period did not show substantial differences between seed mixtures on erosion processes during the first weeks after restoration.

The use of cover crops and in recent time also nursery grasses as additional protection against erosion is often used for restoration activities. Due to positive, longstanding experiences of restoration companies, those techniques were compared to normal hand sowing. Again we noticed that the admixture of fast growing components did not have positive influence on surface runoff and soil erosion. Compared to 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. Results obtained clearly showed that the use of cover crops and nursery grasses did not have positive influence in view of a necessary reduction of surface runoff and soil losses during the first weeks after restoration.

Hydroseeding is described as one of the best application techniques for steep slopes with good properties in order to prevent erosion. To our surprise, the comparison of hydroseeding to hand sowing plus cover crop showed comparable results. The hydroseeding was carried out by a professional 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 stabilized gluten, reducing the effect of building a protective layer on soil surface. Even if we take this possible problem into account, results obtained at least indicate a big risk in using this application technique without additional protection of soil surface.

Depending on soil physical properties, climate and altitude, varying characteristics of runoff, infiltration and erosion can be expected (Markart & Kohl 1995). Especially in high altitudes, the main goal behind the choice of a certain application method has to be a reduction of surface runoff and soil erosion to an acceptable degree. A comparison of all used application techniques during our assessments shows clear results. Only an additional cover of soil surface is able to reduce surface runoff and soil losses to an acceptable degree. For our trials in 1999 and 2001-2002 we used a straw mat. But there are a lot of different techniques available that guarantee a sufficient protection of soil surface. Straw mulching, hay mulching, different mats, nets made from jute or coco, three-dimensional mats etc. With the first series of trials, we were not able to work out differences between the materials. But a comparison can be made to results gained from field trials in South Tyrol (Waldner 1999, Graiss 2000). There, erosion was measured for different application techniques with and without covered soil surface, regarding to precipitation. A measurement of surface runoff was not possible. However, differences between the used techniques with covered soil surface (straw, hay, with or without bitumen emulsion to glue the organic matter) were low. The proportion between soil losses of covered plots to hand sowing plus cover crop (average proportion of 1:110) is comparable to the results of our project.

5. Conclusion

Our assessment on vegetation cover of the plots showed, that under average conditions of high altitudes the necessary minimum vegetation cover between 70 % and 80 % can be reached the second vegetation period at the earliest. This requires application techniques with sufficient protection of soil surface for the first vegetation period.

During the second vegetation period, differences between used application technique are still visible but a satisfying developed vegetation cover reduces the total surface runoff and soil losses to an acceptable degree.

Due to the faster germination and early growth of commercial varieties, an increase of surface runoff and soil losses the weeks after sowing was expected for indigenous seed mixtures. However, the harsh conditions in high altitudes (low soil and air temperature, short vegetation period, frequent frost), causing environmental stress to the vegetation, reduced the competitiveness of commercial forage grasses and herbs and neutralized their greater productivity. Results obtained did not show substantial differences between seed mixtures on erosion processes during the first weeks after restoration. However, to reach sustainable vegetation with a cover exceeding the minimum requirement of 80 %, the use of indigenous seed mixtures would be a precondition.

The use of cover crops and nursery grasses did not have positive influence in view of a necessary reduction of surface runoff and soil losses during the first weeks after restoration. The environmental stress compensated also their capability of fast early growth, reducing the positive effects towards zero.

The comparison of hydroseeding to a simple hand sowing plus cover crop showed comparable results. This at least indicated a big risk in using this application technique in high altitudes without additional protection of soil surface.

A general comparison of all used application techniques during our assessments showed clear results. Only an additional cover of soil surface was able to reduce surface runoff and soil losses to an acceptable degree. Straw mulching as well as hay mulching, different mats, nets made from jute or coco, three-dimensional mats etc. could be applied. The use of application techniques with a satisfying additional cover of soil surface should be generally recommended for restoration of slopes in high altitudes.

6. Acknowledgements

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7. References

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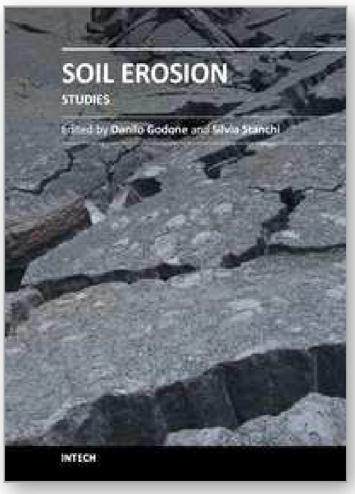

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Soil erosion affects a large part of the Earth surface, and accelerated soil erosion is recognized as one of the main soil threats, compromising soil productive and protective functions. The land management in areas affected by soil erosion is a relevant issue for landscape and ecosystems preservation. In this book we collected a series of papers on erosion, not focusing on agronomic implications, but on a variety of other relevant aspects of the erosion phenomena. The book is divided into three sections: i) various implications of land management in arid and semiarid ecosystems, ii) erosion modeling and experimental studies; iii) other applications (e.g. geoscience, engineering). The book covers a wide range of erosion-related themes from a variety of points of view (assessment, modeling, mitigation, best practices etc.).

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