CHARACTERISTICS OF ARTIFICIAL SNOW AND ITS EFFECT ON VEGETATION

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ABSTRACT: The winter and early spring environment of plants under ski slopes is physically and chemically changed due to grooming and the addition of artificial snow. As the vegetation cover and hence alternative land uses (agriculture) or laws may be affected, it is important to know a potential impact on the ecosystem. To relate and explain plant performance with snow cover characteristics, we investigate their interactions in alpine ski areas.
In winter 1999/2000 we studied snow depth, density and soil surface temperature in ten different ski areas in the Swiss Alps. In summer 2000, a vegetation survey was performed in the same place. To achieve paired data, we studied both artificial ski slope and adjacent ungroomed natural snow cover as a control in every ski area.
Snow depth and snow density showed considerable differences between slopes and control plots. The snow cover on artificial ski slopes reached on average 120% of the natural snow cover. Similarly, density of the ski slopes was 135% higher than in the nearby natural snow. Temperature measured on the soil surface showed no consistent difference between artificial snow ski slope and natural snow. However in spring, the snow stayed 19 days longer on the slopes. Overall comparison of the vegetation relevées showed no difference in number of species between artificial snow and control. But, vegetation cover of functional groups was distinctly changed. The amount of herbs and small shrubs was reduced, while legumes showed a higher cover on artificial snow slopes. Similarly, the amount of open soil was increased on slopes.
The physical conditions of the snow cover on ski slopes are much changed through grooming and addition of artificial snow. A change in species composition indicates that some plant species may profit of the changed winter environment, while others are suppressed. Further experiments will be performed, to reveal specifically cause and effect of artificial snow and grooming on alpine plants. On base of this information, we finally will develop methods of environmentally sound ski slope preparation.

KEY WORDS: Artificial Snow, Snow Density, Snow Depth, Ski Slopes, Temperature, Vegetation

1. INTRODUCTION

In alpine ski areas, the winter and early spring environment of plants and soil is changed through grooming of the snow cover and the addition of artificial snow (Broggi and Willi 1989). In Switzerland, most ski slopes are used in summer as pastures or as hay fields. Hence the use of the land as ski slopes in winter should minimize the impact on summer uses. In addition, the impact of grooming may not be coherent with federal and state laws, e.g. the protection of nature and environment. Therefore, it is important to know the effect of artificial snow on underlying vegetation in alpine ski areas.
Through the use of artificial snow, the physical as well as chemical aspects differ from the natural snow cover. Snow grains of artificial snow are spherical and hence the snow is more dense than it would be naturally. Grooming increases density additionally. An increased density of the snow cover causes an increased temperature conductivity. Hence, wintering plants and soil may freeze during cold winter days. Frost may directly harm plant cells through crystallization of water in the tissue. In addition, plants may suffer from reduced nutrient supply due to reduced biological activity in the frozen soil (Hofmann and Pfitscher 1982). The increased density of the snow cover may also lead to a changed air quality on the soil surface. It is supposed, that increased CO_2 and N_2O levels develop, favoring plant pathogens (Cernusca 1989, Newesely et al. 1994).
While producing snow, additional water and ions are brought into the system (Hegg 1992, Jones and Devarennes 1995). Water input enhances the availability of this resource for

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plants and hence changes growth conditions. For producing snow, water is taken from nearby streams or reservoirs. These water sources show an increased amount of minerals compared to atmospheric precipitation. Therefore, plants on the slopes face additional minerals. Through the additional snow mass, a prolongation of the snow cover in spring is expected, which may shorten the growing season of plants.
Under these physically and chemically changed snow conditions qualitative and quantitative reactions of the vegetation are expected. Species composition and biomass production were found to be changed (e.g. Holaus and Partl 1994, Kammer 1989). However, the attribution of specific cause and effect among interactions between artificial snow and vegetation was rarely possible.
In 1999 we started a project on the effect of artificial snow on the environment. Here we present the first results on snow depth, density and soil surface temperature as well as vegetation aspects of ski slopes with artificial snow in comparison to the nearby unmanaged snow cover.

2. METHODS

To characterize the winter environment of plants under ski slopes with artificial snow, snow depth, snow density and soil surface temperature were measured during winter 1999/2000. Ten different ski areas in the Swiss Alps were sampled. The slopes were on altitudes between 1150 m and 2515 m a.s.l. Half of the sampled ski stations laid above, half of them below potential tree line (2000 m a.s.l.). To achieve comparable data, the study was performed each on a ski slope of artificial snow and a nearby control plot with a natural, unmanaged snow cover. Both plots per ski area had the same altitude and topography, and hence potentially the same vegetation aspect.
In all plots selected, soil surface temperature was measured from October 1999 through June 2000. Temperature was recorded every hour with UTL loggers. Snow depth and snow density were measured one day in winter, between February 27 and march 6. The density of the snow was determined by weighing a snow core with a defined volume. In this way, the density of the snow was measured along the whole profile. Snow depth was derived by the length of the total snow core drilled.
By comparing the products of depth and density per snow type, the additional water input due to artificial snowing was calculated. On base of the temperature data, duration of the snow cover was defined. Snow melt was set as the day, when the temperature difference between minimum and maximum had reached more than five degrees.
In summer 2000, between June 23 and August 8, vegetation relevées were performed in the same plots where winter investigations took place. Plant species and their cover were determined on an area of 16 m^2 each. Total plant cover was divided into functional groups (grass, herbs, small shrubs, legumes, moss) and potentially bare soil. Differences in average values were tested with an analysis of variance.

3. RESULTS AND DISCUSSION

Both snow parameters measured, depth and density showed considerable differences between ski slopes and control plots, while temperature of the soil surface showed no consistent pattern.

3.1. Snow depth

The snow was found to be higher on artificial ski slopes than on the control with natural snow (FIGURE 1). On average, snow depth was reaching 139 cm on the ski slopes with artificial snow and 110 cm in a natural snow cover. Hence, snow piles up 20% higher on the slopes compared to the natural snow cover. As a consequence of the additional mass, the snow cover needs more energy to melt.

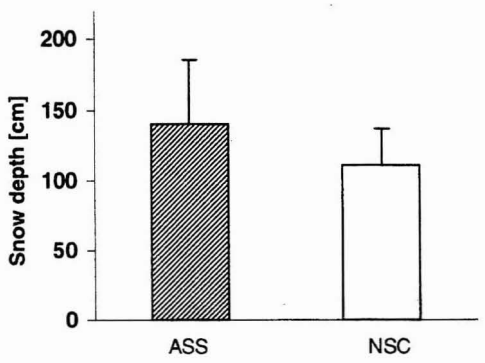


FIGURE 1. Average depth of the snow cover of the artificial snow slopes (ASS) and the corresponding natural snow cover (NSC). The snow piles up considerably higher on ski slopes with artificial snow than on controls (trend, $p<0.1$). On average, the artificial snow cover reaches 120% of the control.

3.2. Snow density

The density of the snow was found to be distinctly higher on ski slopes than in natural snow. Snow samples from the ski slopes were reaching an average of 524.8 kg/m³, whereas 353.3 kg/m³ were recorded for natural snow (FIGURE 2). Hence, snow density values were 135% on slopes compared to the controls.

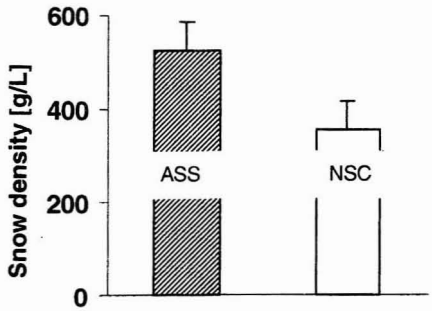


FIGURE 2. Average density of the snow samples collected on ski slopes with artificial snow (ASS) in comparison to the samples of the nearby natural snow cover (NSC). Artificial snow reaches 135% of the density of the unmanaged natural snow cover ($p<0.001$).

3.3. Water input

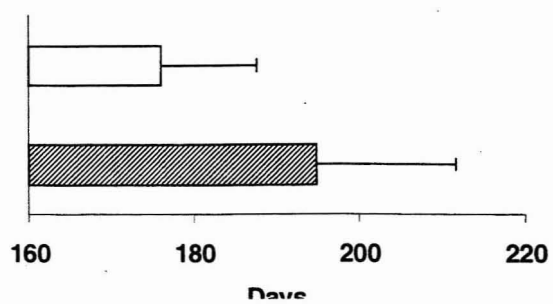
On base of the average snow depth and density values, an average additional water input through artificial snow can be estimated. Hence, on average an additional 87% of the natural precipitation water is brought in by artificial snow making.

3.4. Soil surface temperature

The soil surface temperatures showed no clear pattern comparing ski slopes with artificial snow and natural snow controls. In general, according to heat flux, the higher the snow piled up and the less dense the snow cover was, the less days with frost occurred. The increased depth of the artificial snow cover seems to overcome increased temperature conductivity due to the high density.

3.5. Duration of the snow cover

In contrast to the temperature below the snow, the duration of the snow cover showed clear differences between artificial snow slopes and



ural snow controls. In general, the artificial
NSC w slope was 19 days longer covered by
w compared to control plots (FIGURE 3).
nsequently for the plants under an artificial
ASS slope, growth starts later in spring, and the
e for energy gain and reproduction is
rtened.

URE 3. Average duration of the snow cover of natural snow (NSC) and the artificial snow slopes (ASS). In spring 2000, the snow stayed for 19 days longer on the slopes compared with the natural snow cover ($p<0.01$).

3.6. Vegetation performance

The comparison of vegetation relevées showed no difference in number of species between artificial snow and natural snow plots. Although the number is equal, species composition on ski slopes differs from natural snow controls. Analysis of the vegetation cover revealed differences in functional groups. The percentage cover of herbs and small shrubs is diminished on slopes, whereas the percentage of legumes increased. Grasses and moss were equally frequent under both snow types. A disappearance of small shrubs is most probably due to mechanical damage by grooming. The legumes that are able to fix air nitrogen increased under artificial snow possibly because they can better profit from the input of minerals.

Besides the vegetation cover, the percentage of open soil was higher on artificial snow plots. This bare soil might be a consequence of grooming. (TABLE 1).

TABLE 1. The percentage cover of different functional groups of plants and remaining bare soil is listed. The cover of herbs and woody plants is diminished on the slopes ($p<0.05$), whereas leguminosae became more frequent ($p<0.1$). The amount of plantless bare soil was higher on slopes than in natural snow plots.

	Grass	Herbs	Woody plants	Legumes	Moss	Bare soil
ASS	39.6	26.2	7.8	11.5	3.7	11.2
NSC	39.7	32.5	15.1	4.6	2.5	5.6

4. CONCLUSIONS

Snow depth, snow density and the duration of the snow cover of the ten alpine ski areas investigated in the Swiss Alps show

considerable differences between ski slopes and the nearby ungroomed natural snow cover. On artificial snow ski slopes, depth, density and duration of the snow cover are increased, and vegetation composition is changed. However, to be able to assign specific cause and effect in the interactions between the artificial snow cover and the underlying vegetation, experiments under controlled conditions are necessary. In the coming winter, we will set up experiments to test the effect of the delayed snow. Similarly, we examine the influence of the increased amount of minerals in artificial snow on the performance of plants. With the approach of comparative studies, experiments and theory we hope to finally be able to propose methods of environmentally sound ski slope preparation.

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6. REFERENCES

Broggi, M. F. and G. Willi (1989). Beschneiungsanlagen im Widerstreit der Interessen. CIPRA, Vaduz.

Cernusca, A. (1989). Zur Schneestruktur beschneiter Flächen - Einflussfaktoren und ökologische Auswirkungen auf Vegetation und Boden im Pistenbereich. Motor im Schnee 5: 13-17.

Hegg, O. (1992). Auswirkungen von Schneekanonen auf Vegetation und Boden. In: E. Gnaiger and J. Kautzky, eds. Umwelt und Tourismus. Reihe des Umweltforums Innsbruck, pp 200-202.

Hofmann, J. and A. Pfitscher (1982) Veränderungen der mikrobiellen Aktivität in Böden unter Skipisten und Wanderwegen. Pedobiologia 23: 105-111.

Holaus, K. and C. Partl (1994). Beschneiung von Dauergrünland - Auswirkungen auf Pflanzenbestand, Massenbildung und Bodenstruktur. Verhandlungen der Gesellschaft für Ökologie 23: 269-276.

Jones, H. G., and G. Devarennes (1995). The chemistry of artificial snow and its influence on the germination of mountain flora. Pp 355-360, IAHS Publ.

Kammer, P. (1989). Auswirkungen von Kunstschnee auf subalpine Rasenvegetation. P 180, Systematisch-geobotanisches Institut, Universität Bern, Bern.

Newesely, C., A. Cernusca, and M. Bodner (1994). Entstehung und Auswirkung von Sauerstoffmangel im Bereich unterschiedlich präparierter Schipisten. Verhandlungen der Gesellschaft für Ökologie 23: 277-282.