SOIL EROSION CAUSED BY SNOW AVALANCHES: PRELIMINARY RESULTS OF TWO CASE STUDIES IN THE AOSTA VALLEY (NW-ITALY)

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ABSTRACT: Snow avalanches exert considerable erosive forces on soils, which may be torn open and scraped away, especially in the transition zone, as a result of the ground shear stress. Soil material mixes up with the avalanche body and is normally deposited at the bottom of the valley, originating specific forms of erosion and accumulative topography. The quantity of soil material eroded and accumulated depends on avalanche characteristics (e.g. dimension, full depth dry or wet avalanches) and on morphological features (e.g. channelled or unconfined avalanches, slope angle), but also on soil properties and vegetation cover.

The monitoring of two channelled avalanche cones in the Aosta Valley (NW-Italy) was realized in order to assess the erosive impact of avalanches on soil. Sediment concentration estimates and measurements of the avalanche deposit volumes were used to calculate the total sediment load. The sediments collected were separated into the fine earth (<2mm) and large (>2mm) organic and mineral fractions. Preliminary results obtained from the winter season 2003-2004 showed that the amount of upwards eroded material deposited on the pre-existent soil at the foot of the avalanche paths was constituted mainly by the fine earth fraction. The organic carbon and total nitrogen content in the fine earth fraction was respectively equal to 8-9% and 0.39-0.42%. The total sediment load was estimated equal to 31 and 25 t/ha, with the greatest value recorded in the smallest avalanche cone. The considerable avalanche sediment deposits together with the great amount of water released during the snowmelt may influence the soil development in the deposition zone, contributing to determine specific pedo-environmental conditions.

KEYWORDS: soil properties, avalanche deposits, Alps, organic carbon, total nitrogen

1. INTRODUCTION

Snow avalanche deposits are common in Alpine environments. They result almost exclusively from dirty snow avalanches which erode, transport and deposit soil, organic and rock debris. Most avalanches start as snow avalanches which then pick up varying amount of sediments en route, ultimately becoming debris avalanches or slides. These are sometimes termed “dirty avalanches” (Rapp, 1960) or “mixed avalanches” (Wasburn, 1979).

Dense avalanches have a high shear strength, and their “rigid plugs” can support clasts as large as boulders (Blikra and Sæmundson, 1998).

Where avalanches involve the whole depth of snow or run onto snow-free areas they may incorporate large amounts of debris (Luckman, 1978).

The rock and soil material transported by the avalanches come from the erosion of the underlying bedrock or meadow in the starting zone or along the transition zone (Gardner, 1983; Jomelli and Bertran, 2001). The vegetation cover usually protects the underlying surface from erosion (Luckman B.H., 1978). However, complex soil profile morphologies may occur along an avalanche path with both buried or truncated horizons (King and Brewster, 1978).

The effects on soils are dependent on avalanche type. If full-depth avalanches predominate, then in the transition zone the soils are stripped off, appear fragmented or are highly degraded (Freppaz et al., 2003). If surfaces avalanches predominate, then soils in the transition zone are better preserved and the avalanche channels can be completely grass-covered (Bozhinskiy and Losev, 1998).

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Previously published studies on this topic investigate the sediment transported by the avalanche events in the deposition zone and rely on various observation periods (e.g. Ackroyd, 1987; Bell et al., 1990; Kohl et al., 2001; Heckman et al., 2005). Most of the previous studies have dealt only with the transport of debris. Fewer studies have characterized the fine earth fraction (< 2mm) and the quality of such material (e.g. carbon and nitrogen content) in relation to the soil development in the deposition area, where the moisture and cold accumulation by the avalanche body are all manifested at their maximum extent and may contribute to determine specific pedo-environmental conditions. Avalanche deposits are usually separated by soil horizons and some of them have an organic - rich matrix. Blikra and Sæmundson (1998) tried to estimate the avalanche frequency by the analysis of sedimentary successions.

The objective of this paper is to quantify and describe the sediments transported by the avalanche events, focusing mainly on the composition of the fine earth fraction.

2. STUDY SITES

The monitoring of two channelled avalanche cones was carried out in the Aosta Valley (NW-Italy) from Winter 2003-2004. The two areas are characterized by different track lengths and climatic patterns, leading therefore to different type of avalanches.

2.1 Study site I

The study site I (Tschemenoal) is located in the East part of the Vallée d'Aoste Region, about 15 km S from Mt. Rose Massif (4635 m a.s.l.) and 60 km ENE from Aosta (Figure 1). The area is characterized by a precipitation maximum during Spring, with an average snow height of 374 cm at 2000 m a.s.l. for a return period of 30 years (SMS, 2003; Barbolini, in press).

It is a big-size partly-channelled avalanche path, with a total vertical drop of about 1600 m, and a track length of about 2200 m; the average inclination of the whole path is about 37° (Figure 2). The release zone is identified in a large area (about 0.03 km^2), mainly made up of altitude grasslands (e.g. *Festuca varia Haenke*) and shrubs (*Juniperus sp., Rhododendron ferrugineum L.*).

The collected data referred to the avalanche event of the 19th January 2004 (Figure 2).

2.2 Study site II

The study site II (Lavancher) is located in the North-West part of the Vallée d'Aoste Region about 15 km SE from Mt. Blanc Massif (4810 m asl) and 20 km WNW from Aosta (Figure 1).

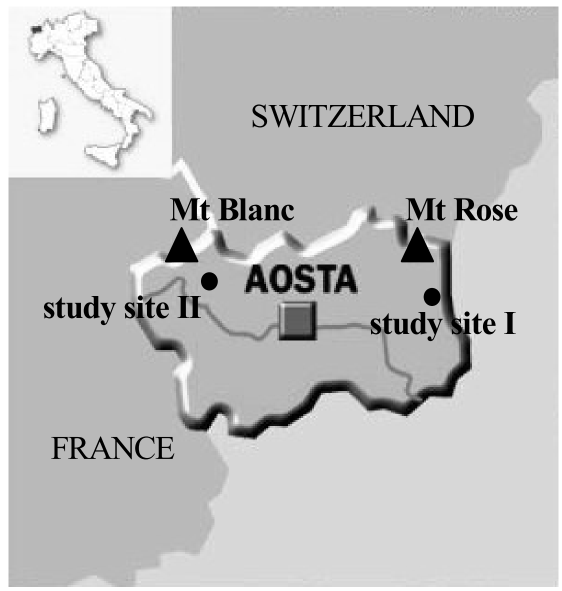

Figure 1. Localization of the study sites.

The area is characterized by a precipitation maximum during the Autumn, with an average snow height of 374 cm at 2000 m a.s.l. for a return period of 30 years (SMS, 2003; Barbolini, in press).

It is a big-size partly-channelled site, with a total vertical drop of about 2000 m, and a track length of about 4500 m; the average inclination of the whole path is about 30° (Table 1). The upper collecting basin is represented by an ample (about 2.5 km^2) and rather homogeneous open bowl, mostly made up with high altitude grasslands (Barbolini et al., 2000).

The collected data referred to the avalanche event of the 5th March 2006 (Figure 3).

		Site I	Site II
Aspect		E	SE
Vertical fall	m	1600	2000
Gradients			
Mean	deg	37	30
Starting zone	deg	38	42
Transition zone	deg	28	38
Deposition zone	deg	10	15
Basin area	m^2	415000	3500000

Table 1. Avalanche path morphometry.

3. METHODS

The characteristics of the soils along the avalanche paths have been determined through a pedological investigation. The soils were described (Soil Survey Staff, 1951), sampled and classified according to the USDA Soil Taxonomy (2006).

During all winter, as soon as the risk of further avalanching was considered minimal, the snow deposits of the avalanche events have been mapped in the field.

Figure 2. Avalanche deposit in study site I (19th January 2004).

For the purpose of volumetric and sediment estimation, each avalanche deposit was surveyed several times (**site I**: 19th March 2004, 2nd April 2004, 26th April 2004, 19th May 2004; **site II**: 30th March 2006, 12th April 2006, 24th April 2006, 29th April 2006, 13th May 2006, 8th June 2006).

The method employed to determine avalanche deposit volume have been proposed by Bell et al. (1990), previously discussed and evaluated by Schaerer (1988).

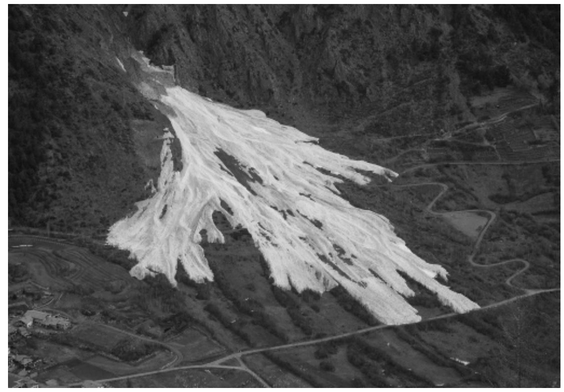

Figure 3. Avalanche deposit in study site II (5th March 2006).

Snow sediment concentration in the first 10 cm of the avalanche deposit was estimated coring vertically at different times (steel core: 200 mL; 5 cm diameter). The sampling have been done according to a grid square of 50 m^2. In site II the first two samplings have been carried out on a grid square of 1000 m^2.

The snow samples were melted and filtered (0.45 μm) and the sediments were dried and weighed. The measured sediment concentrations were then used in conjunction with the subsurface volume (surface area * 0.1 m depth) of the last measured avalanche deposit in order to produce estimates of the total sediment loads of the deposits.

The collected sediments were sieved with 2 mm mesh in order to separate the rocks and the large organic debris from the fine earth fraction (<2 mm). The total nitrogen and the organic carbon in the fine earth fraction were measured on the milled oven-dry samples using a CHN analyzer (Carlo-Erba, Turin, Italy).

Snow density measurements in each sampling site at 10 cm depth were made using a 0.5 Liter stainless steel cutter (Cagnati A., 2003).

Statistical analysis of the data was carried out using SPSS software.

4. RESULTS

4.1. Study site I

The avalanche deposit volume was estimated equal to 5400 m^3. The avalanche deposit was constituted by angular blocks or rounded clods, 5-50 cm in diameter. The snow density increased from 640 kg/m^3 at the first sampling to 685 kg/m^3 in correspondence of the last one.

The first snow sampling showed an average total sediment concentration equal to 0.39 (± 0.21) kg/m^3, the second one showed a total concentration of 0.50 (± 0.47) kg/m^3, the third one a value of 5.2 kg/m^3 (± 3.0) kg/m^3 and the fourth one of 31.1 (± 19.9) kg/m^3. The sediment concentration was significantly higher ($p < 0.05$) in the last sampling while no significant differences were recorded between the first three samplings.

The surface of the deposit decreased from 900 m^2 of the first sampling to 800 m^2 of the second one, 700 m^2 of the third one and 350 m^2 of the last one. The total sediments load was estimated equal to 3.1 kg/m^2. Considering an average bulk density of the sediment equal to 1400 kg/m^3 the mean sediment accumulation was equal to 2.2 mm.

The soils along the avalanche path were classified as Inceptisols and Entisols.

Whole clods of soil (25 cm length) and some big stones (5-15 cm), located on the avalanche deposit surface, were found in the deposition zone. The percentage of the different fractions measured in the sediments are reported in Figure 4. The fine earth represented the 58% of the sediment and was constituted by the 8 (± 0.87) % of organic carbon and by the 0.39 (± 0.03) % of total nitrogen.

The amount of water released in the deposition zone during the snowmelt was estimated equal to 3456 m^3.

4.2. Study site II

The avalanche deposit volume was estimated equal to 70.000 m^3. The snow density increased from 580 kg/m^3 at the first sampling to 630 kg/m^3 in correspondence of the last one

The first snow sampling showed an average sediment concentration of 17.9 (± 17.3) kg/m^3, the second one of 11.8 (± 8.1), the third one of 16.6 (± 11.0) kg/m^3, the fourth one of 20.7 (± 20.4) kg/m^3, the fifth one of 16.1 (± 3.3) kg/m^3 and the sixth one of 25.2 (± 8.5) kg/ m^3.

The sediment concentration was not significantly different in the different samplings ($p < 0.05$).

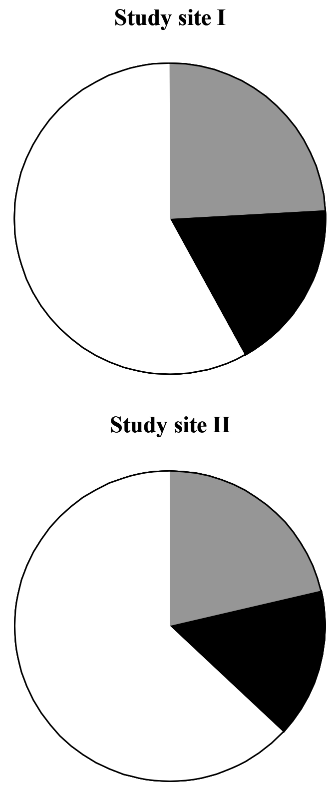

Figure 4 Average composition of the snow sediments (in %) in the deposits of the two study sites. Rocks (> 2mm) (black), organic debris (> 2mm) (gray), fine earth (< 2mm) (white).

The soils along the avalanche path were classified as Inceptisols and Entisols.

The surface of the deposit decreased from 61400 m^2 of the first sampling to 315 m^2 of the last sampling. In this study site the total sediments load was lower than in study site I and estimated equal to 2.5 kg/m^2. The mean sediment accumulation was equal to 1.8 mm.

The percentages of the different fractions that constituted the sediments are reported in Figure 4. As measured for the study site I, the fine earth constituted the most part of the sediment (63%), with an average organic carbon concentration equal to 9 (± 0.91) % and a total nitrogen concentration of 0.42 (± 0.02) %.

The amount of water released in the deposition zone during the snowmelt was estimated equal to 40600 m^3.

5. DISCUSSION

The amount of sediments transported by the avalanches was not proportional to avalanche size: the greatest value was found in site I, the smallest one. Luckman (1978) and Ackroyd (1986) have shown that, given optimum environmental factors (e.g. type of avalanche, debris available), even moderately sized avalanche can transport an exceptional quantity of debris. There were no evidences that the sediments were transported there by any other means than the avalanches.

The measured values (31 and 25 t/ha respectively in study site I and study site II) were in accordance with what reported by Bozhinskiy and Losev (1998), who indicated an annual removal of mineral material by avalanches per 1ha of the deposition and transition zones between less than 1t and more than 100t, according to the geographical conditions and geological structure of the terrain. The sampling scheme employed in this work is more sensitive to small clasts and fine material, therefore large clasts (> 5 cm diameter) have gone unmeasured although they may have contributed significantly to the total sediment load.

Considerable variability in sediments concentration was shown in all the sampling times. In particular, a significant increase in sediments concentration during Spring time was observed in site I and attributed to the progressive surface melting and the accumulation of the transported material, as reported by Bell et al. (1990). Moreover, the increase of sediment concentration from the avalanche deposit as the snowmelt proceeds reveals that the sediments are not accumulated only on the surface of the deposit, but also at greater depth. This might indicate that some quantity of sediment is transported at the interface between avalanche flow and soil surface (Jomelli and Bertran, 2001).

The large organic debris constituted about the 20% of the sediments, and was represented mainly by roots and grass cover. Turfs and grass may be contained in the snow clods, which are formed during the avalanche motion (Bozhinskiy and Losev, 1998).

The measured quantities of fine earth (58-63%) were higher than what reported by Heckmann et al. (2002) who found a percentage of about 30% in an area constituted mainly by loamy soils. The high content of fine earth in the material found in these avalanche deposits confirms that both catchment areas are located on slopes with soil development and that not only the surface of the avalanche path was eroded, but also the deeper horizons (Figure 5).

Figure 5 Soil surface in the avalanche track of the study site I.

Whole clods of soil were torn out along the avalanche path and deposited at the bottom of the valley. Such eroded areas, as well as the deposits, without vegetation, may become subject to soil erosion by water also during snowmelt and during summer storms (Kohl et al., 2001 and Heckmann et al., 2002) (Figure 5).

The fine earth fraction was constituted by the 8-9 % of organic carbon and by the 0.39-0.42 % of total nitrogen. Therefore, it may significantly contribute to soil development in the avalanche deposition zone, as reported also for some case studies in Pakistan by de Scally and Gardner (1987).

The mean sediment accumulation in the deposition zone ranged between 1.8 and 2.2 mm, values in accordance with what reported by Gardner (1983), who, for a wet snow avalanche, estimated an accretion over the surface occupied by the avalanche deposit of 2 mm and Luckman (1988), who indicates mean debris accumulation rates of 5 mm/year in the Canadian Rockies over the 1969-81 period.

The average snow density measured in both deposition zones was in accordance with what reported by Ackroyd (1986), who, for wet snow avalanches, reported a value of 700 kg/m^3. The water input during the snowmelt was considerable in both study sites and, together with the sediments load, contribute to determine specific pedo-environmental conditions in the deposition zone.

6. CONCLUSIONS AND FURTHER WORK

The preliminary results obtained from these two study areas showed that the sediment transport by snow avalanches was not proportional to avalanche size. The amount of material transported by avalanches in the deposition zone was equal to several t/ha of sediments. In both avalanche cones the fine earth fraction represented the main fraction of the sediments and was constituted of ca. 10% of organic carbon and of ca. 0.40% of total nitrogen, which, together with the great amount of water released in the deposition zone, contribute to determine specific pedo-environmental conditions.

In the future, the proposal is to continue the monitoring of the two avalanche sites to implement the database and therefore be able to perform a better evaluation of the soil erosion process. The assessment of the aggregate stability of the soils along the avalanche paths will be carried out in order to understand where the main source of the transported material is. Moreover, the measurements of the amount of nutrients in the avalanche snow deposit will allow to improve the estimation of the nutrient load to the soils in the deposition zone.

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