Snow Management in Agricultural Landscapes

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Abstract. Snow accumulation conditions in Russian and northern Kazakhstan crop productive areas are examined based upon experimental study results. Snow drifting and evaporation from snow were studied particularly. The local snow accumulation coefficient (LSAC) is defined as the ratio of snow water equivalent (SWE) and corrected winter precipitation minus evaporation from snow. The LSACs were mapped, as well as snow evaporation, to detect those areas with prevalent snow accumulation and snow drifting. Field studies has shown, that some water supplement is observed and overland flow decreases only when the frozen soil could be impermeable without snow retention. In other cases the local efficiency of such snow management will be negligible due to increasing snow evaporation from rugged and dirty snow.

Introduction

Research in snow hydrology has a manifold applications including those which are of importance to the climatic studies. In particular, the snow management (Federer *et al*., 1972) is to regulate snow, its spatial re-location and melting to provide a profitable crop yield. Snow retention measures throughout Russia and Kazakhstan were mainly to decrease the snow drifting and optimise thermal regime of soils in regions with winter crop agriculture (Shul'gin, 1986).

To estimate the efficiency of the snow retention, the State Hydrological Institute (SHI) undertook special field studies in northern Kazakhstan. We have developed a new methodology of the snow retention based on the experimental studies in snow physics and the water budget. As a result (Delarov *et al*., 1985, Shutov, 1990, Shutov and Kaljuzny, 1988), we may affirm that retention of the snow cover on agricultural fields can provide an additional water yield due to decreasing the snow removal and promote for soil water replenishment. It is in practice particularly in northern Kazakhstan and Mongolia where the so-called snow ridges are built by using a snow plough. Runoff creating surface on a slope imagines then as a regular strips with different infiltration capacity of underlying soil. Melt water percolates that well permeable soil under the snow ridges as well as below deep snowdrifts captured by special snow fences.

Field studies taken place there has shown, that some water supplement is observed and overland flow decreases only when the frozen soil could locally be impermeable without any snow retention. In other cases the efficiency of such snow management will be negligible. Moreover, we can expect additional losses due to increasing snow evaporation from rugged and dirty snow particularly from steep south-side slopes. Predicting these effects and decision making may be enabled just after mid-of-winter snow surveys.

Snow drifting and local snow accumulation

When (as in Russia and Kazakhstan) the plains are dissected by ravines and hollows, the substantial non-homogeneity in the snow cover accumulation takes place mainly conditioned by storm snow drifting. This affects overland flow and thermal and water regimes of the soils. The ratio of the snow water content at a local site and that spatially averaged for whole plain fields we called the Local Snow Accumulation Coefficient LSAC (Shutov, 2000a). Its values can amount to about 3 and more, depending on the wind speed and on geomorphic structure of the area.

The LSAC can then be obtained from meteorological data and expressed as the ratio of snow water content to the sum of precipitation minus evaporation and melt water losses. The LSAC can be used as the basic criterion which allows to map snow cover accumulation over an area of interest. Resulting from that, the calculation and mapping have been done of LSACs (Petropavlovskaja and Kaljuzny, 1986) for the northern Kazakhstan. As was found, the annually averaged LSACs are among 0,6 and 0,9 for most of the area varied inter-annually while the seasonal snow budgets can be either positive or negative as conditioned by relief, wind directions prevailed while snow storms.

Evaporation from snow

We have conducted the measurements of evaporation from snow by using the shallow pan lysimeters 500 cm^2 by 6 cm depth, so these water losses can be reliably determined. We have taken into account all the affected factors: solar radiation income, air humidity, wind speed, surface albedo and aerodynamic roughness of snow cover surface. As a result of experiments (Shutov, 1991, 1997), we have found that snow evaporation depends on solar radiation. Besides, the snow evaporation depends on wind velocity and the roughness of the surface. The equation for it becomes alike that offered by Penman. Profile measurements were shown that the roughness factor for rugged surface due to snow ploughing is mush more than that for intact snow surface. Thereby, the turbulent transfer "snow-to-atmosphere" becomes intensive. We have also studied the relationship between snow evaporation and snow pack density (Delarov *et al*., 1985), found it very complex that closely depends on the thermal gradient and extinction of solar radiation flux within snow pack. Based on the data obtained, we calculated and mapped (Shutov, 1990, 1991) evaporation from the natural snow cover and the evaporation losses occurred by snow management.

Contamination of snow

When studying snow, we encounter another problem which is a human impact on snow cover in urban areas strongly affected snowmelt and water resources generating respectively. Concentration of dust can vary from 10 for the freshest snow cover up to 500 gram per 1 m^2 near highways (Glasovsky *et al*., 1983). We undertook special measurements of the snow surface albedo with use of portable short-wave radiometer on experimental plots with intact and artificially contaminant snow pack. The concentration of coal ashes with admixed fine soil particles on different experimental plots varied from 20 to 500 gram per 1 m^2. As a result, the non-linear relationship has been obtained between snow surface albedo and concentration. It was approximated (Shutov, 1991, 1997) with a power function. The respective equation can be used when calculation of snowmelt by heat balance was needed to be performed by an airborne snow cover monitoring. As was found, the role of surface albedo for a dirty snow increases by radiation-induced snow melt which is usual to the prairies. The artificial contamination of snow can make a success there as an effective reduction of excessive snow melt rates to prevent rapid surface runoff and soil water erosion.

Snow and the soil water budget

Considering a large-scale efficiency of the snow management we need to define the basic components of water budget of arable lands: the snow water content H, snow evaporation E and soil water content W or soil water replenishment ΔW during snowmelt period. Positive effects of snow retention will be determined by taken interrelations among them into account. In fact, if $H < E$ then any snow retentive activity is meaningless. On the other hand, when $H > (\Delta W + E)$, i.e. snow water content exceeds the potential soil moisture deficit, we must concentrate efforts on how to increase soil permeability by special tillage. Another criterion is how infiltration rate I differs from the potential water capacity defined as (FC-W+E), where FC is field capacity of the soil.

Generally the decision making is shown in the **Table** below.

Criteria		Decision
Thermal	Water balance	
T>TF		Snow retention is only to decrease snow drifting
T<TF	I > (FC-W+E)	Snow retention is meaningless
T<TF	I < (FC-W+E) along with ΔI>ΔE	Snow retention is necessary
	I < (FC-W+E) along with ΔI<ΔE	Snow retention is not expedient

Conditions in Russian *Chernozem* prairies are near to the second case, so there is a requirement for a deep plough of clay soils when there are deeply negative freezing temperatures (TF). In opposite, northern Kazakhstan is a wide region of potential efficiency of the snow retention under conditions when E < H and H < (ΔW + E). The extra-arid Mongolian plains, where the problem of soil water conservation for farming is, are near to the lower limit defined as H = E. There are ultimately low winter precipitation plus intensive evaporation from snow due to powerful solar radiation that is inherent to Mongolian climate (Shutov and Natzagdorj, 1988). Snow cover distributes there unevenly, that is conditioned by great snow drifting everywhere except mountains.

Water replenishment is main of the suggested results of the snow management. We assumed that the slope with snow ridges across it has an effective mechanism to reduce surface runoff and to reduce removal of contaminants (Kaljuzny *et al*., 1985, Shutov, 1990). This is based on the concept about thermo-physical interrelation between frozen soil and percolated melt water (Kaljuzny and Pavlova, 1981). Resulting from five-annual experimental data, we have clearly discovered empirical relationships between snow accumulation and soil water content (**Figure 1**). We observed that there is no effective soil tillage on a silt loam without any snow management. The latter should be put into practice as provided double more soil water content when ploughing (compare 4 and 7 variances). A light sandy loam cannot be sensitive to the snow plough.

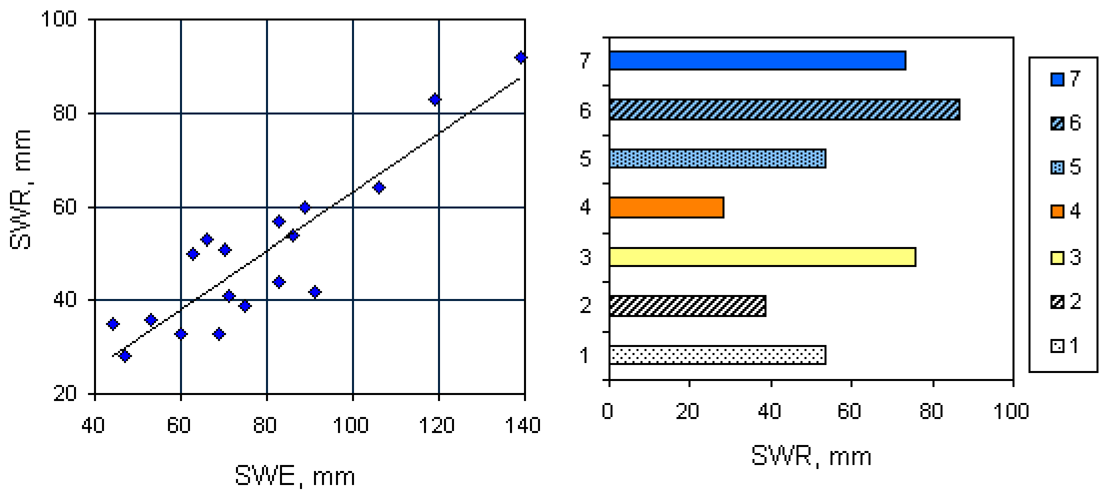

Figure 1. Soil water replenishment (SWR) by snowmelt
SWR as depending on snow water equivalent (left), SWR by various soil and snow (right):
Intact snow cover: virgin soil - sandy loam (1) and silt loam (2); tillage - sandy loam (3) and silt loam (4); snow management: virgin sandy loam (5) and silt loam (6); tillage - silt loam soil (7)

We can also infer that the surface runoff varies under coupled influence of relative soil moisture and snow retention (**Figure 2**). Generally the runoff volume from virgin land increases due to high snow accumulation where snow pack is still undisturbed (where there is no snow management) and, snow retention allow us to modify or to reduce spring runoff and cut off its peak (maximum) so, that may have very important environmental consequences, in particular, for preventing or decreasing outflow of fertilisers from arable lands to local water bodies.

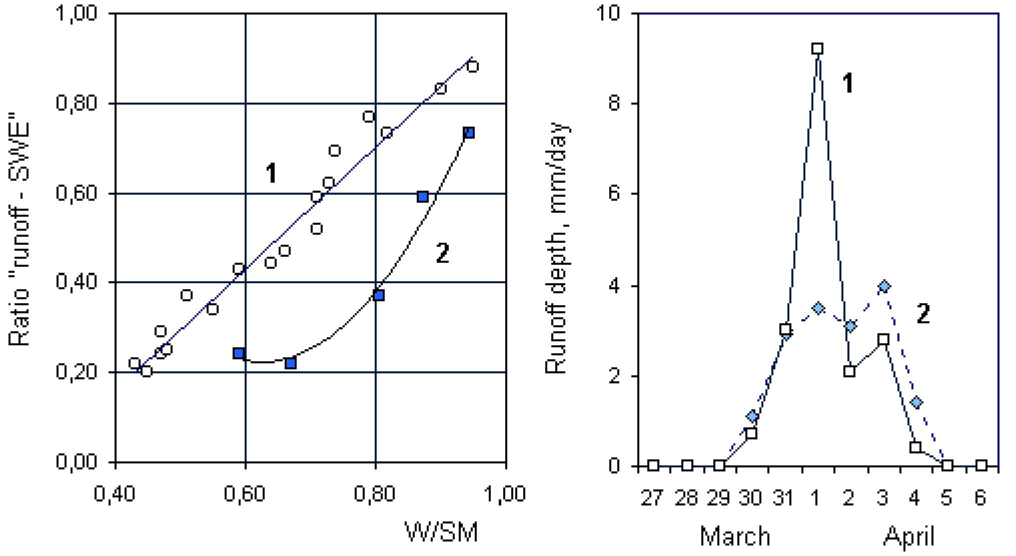

Figure 2. Influence of the snow retention activity on surface runoff
Left: the runoff coefficient ("runoff - SWE" ratio) vs. relative soil moisture (W/SM)
Right: the daily runoff depths (mm) during snow melt period in northern Kazakhstan
1 - control plot with intact snow pack, 2 – experimental plot with snow retention

Now the aim appears how to restrain the contaminant outflow. It can be achieved by special tillage of the soil to improve its infiltration capacity. But, another way is to retain snow on agricultural fields: then it will be to prevent surface flow, not only to keep soil water available for crops.

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