Soil hydrology and soil properties on a partially reforested hillside in the Central Alps

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ABSTRACT: The landscape on southern exposed hillsides in the inneralpine Vinschgau Valley (Northern Italy) is shaped by many thousand years of cultivation. Phases of intensive land use and deforestation were followed by phases of natural regeneration and later by governmental programs of reforestation. The result in the present landscape is the juxtaposition of reforested woodland (RF-areas) and xeric grassland with steppe species (XG-areas) on the same hillside. The scenic and ecological contrast presents ideal conditions for comparative studies in ecology, forest and soil science. On the side of soil science especially the depth and intensity of soil development on the whole hillside have been underrated, whereas the existence of podzolised soils in the reforested area has mostly been overrated so far. One aim of this study was to investigate differences in the development of soils. A further aim was the comparative investigation of the recent hydrological and physical properties as well as the present dynamics of the hillside soils. With regard to that some results of the field and laboratory studies are presented which are contradictory to results of other studies concerning this region.

Keywords: soil hydrology; soil properties; reforestation; water flux; infiltration

The Vinschgau Valley is located in South Tyrol in Northern Italy. The mix of Mediterranean and Central European climatic conditions is a distinction of this region (Grashey-Jansen, Schröder 2009). The annual precipitation averages between 450 mm and 550 mm. Another characteristic of this valley is the extremely different exposition of the hillsides. The northern exposed hillsides are overgrown with thick coniferous forests. The southern exposed hillsides are covered with reforested woods and insular dry grasslands. The existence of totally different vegetation formations side by side is the result of a long cultural landscape history.

The distribution of soil types within the Vinschgau region is very heterogeneous. Most of the soils on the valley floor are gleyic Cambisols, partially calcaric Fluvisols or Gleysols. In general, hillsides are dominated by Leptosols and Cambisols. The geological subsurface of the hillsides is composed of metamorphic rocks. Only the hillside bases are partially covered with sedimentary rock fragments of the alpine trias (Ortlertrias). These calcareous sediments were deposited by the Etsch glacier as side and ground moraine during the last ice age.

The Vinschgau Valley was already populated 7,000 years ago. Because of this long history of settlement the region has changed from natural to cultural landscape. Especially the northern exposed hillsides have been used intensively as grazing land for sheep and goats. The natural vegetation was destroyed by large-scale deforestation and intensive use as pasture. In combination with the warm and dry climate special steppe vegetation has become dominant.

Landslides and avalanches threatened the villages in the valley in the middle of the 19th century recurrently (Fischer 1974), so that reforestation started with several but mostly private programs. Enormous flood damage in 1882 made it necessary to stabilize the protection forest by a first governmental program. By the end of the 19th century the reforestation of 115 ha had been realized. A further aim was to achieve the reforestation of 1,900 ha. But the peasant population offered resistance to avoid the loss of their pastures. Finally this second project of reforestation was cancelled (Sumereder 1959).

Further programs between the two world wars were largely unsuccessful (Kofler-Fuchsberg

2004). In 1951 the third governmental program started with the aim to reforest an area of 1,700 ha (Fischer 1974; Feichter, Staffler 1996). This program was accompanied by a ban on the management of pastures in most areas. Hence there have remained some not reforested grasslands with the typical steppe flora until today.

From 1986 to 2005 a special program of reforestation was executed to change the monocultural coniferous forests into deciduous forests (Feichter 2007a; Grashey-Jansen, Schröder 2011). Fig.1 shows the present situation and the delimitation of the reforested (RF) and xeric grassland (XG-) areas.

MATERIAL AND METHODS

For the study six representative locations on the hillside were selected. Locations 1–3 were situated in the XG-Area and locations 4–6 in the RF-Area (Fig. 1).

Soil samples were taken with 100 cm^3 core cylinders from the horizons in the soil profiles of locations 1–6 (except for some very coarse-textured horizons). Detailed soil profile descriptions (according to AG Boden 2005) and forest botanical mappings (according to the Braun-Blanquet scale) in the field were added by tensiometrical measurements at location 1 in the XG-area and at location 4 in the RF-Area at soil depths of 10 cm, 20 cm and 30 cm according to DIN 19683-5. These depths were chosen for two reasons: to cover the root systems of the steppe vegetation in the XG-area and to compare the water fluxes in topsoil between RF- and XG-area. Soil water tension is an important time series measurement because it provides data regarding the portion of water available to the trees at a given moment in time. For diminishing errors due to the fluctuating inner water column modified tensiometers as proposed by Thalheimer (2003) were used. The use of specially programmed data loggers (Grashey-Jansen 2008) allowed the recording of soil water tensions at hourly intervals. These measurements, conducted at different depths, also aided in calculating the vertical water flux in the soils through calculating hydraulic potential gradients by:

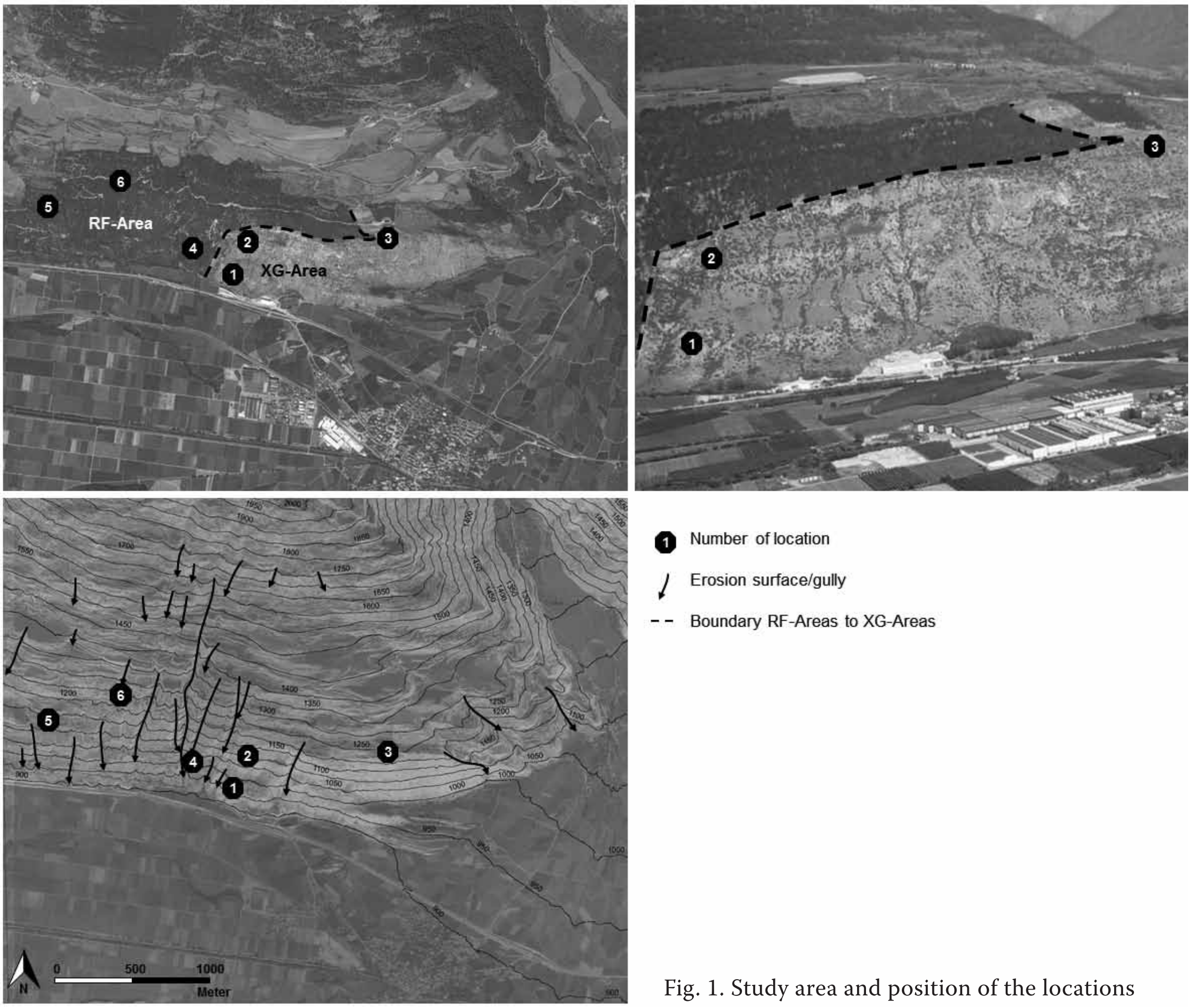

Fig. 1. Study area and position of the locations

$$grad_{\Psi h} = \frac{\Delta_{\Psi h}}{\Delta_Z} = \left[\frac{\Psi_{h_2} - \Psi_{h_1}}{Z_2 - Z_1}\right] \quad (1)$$

where:
$grad_{\Psi h}$ – gradient of hydraulic potential,
Ψ_h – hydraulic potential,
Z – depth of measuring point.

To estimate potential differences in the descendent soil water flux measurements of infiltration were carried out at both locations using a double-ring infiltrometer (DIN 19682-7). The aim of these measurements was the quantification of the infiltration rate i (2) and the *in situ* estimation of the local nearly saturated water flow k_{fn} of the topsoil approximately and specifically for the given location by comparison (Grashey-Jansen 2008).

$$i = \frac{Q}{t \times A} \quad (2)$$

where:
i – infiltration rate (mm·min^{-1}),
Q – volume of infiltration (l),
t – time of infiltration (s),
A – area of the interior cylinder (m^2).

The compaction of the topsoils was measured in transect lines penetrometrically at all locations to quantify the differences. For the probing a cone with 2 cm^2 basal surface was used (diameter 15.96 mm) and the penetration resistance *PR* was calculated by this formula:

$$PR = \frac{P}{BS} \quad (3)$$

where:
PR – penetration resistance (kN·cm^{-2}),
P – pressure (kN),
BS – basal surface (cm^2).

The particle-size analysis for particles < 0.063 mm was done in laboratory by the pipette method and for particles > 0.063 mm by sieving (according to DIN 19683-1, DIN 19683-2, DIN 52098 and DIN 66115-2). All soil samples were pretreated with H_2O_2 (elimination of organic fractions) and with $Na_4P_2O_7 \cdot 10H_2O$ (dispersion medium).

The calculation of the particle-size grading curve was additionally described by the two statistical indices *Cu* (uniformity index) and *So* (sorting index) as follows:

$$Cu = \frac{d_{60}}{d_{10}} \quad (4)$$

$$So = \sqrt{\frac{d_{75}}{d_{25}}} \quad (5)$$

Cu and *So* deliver information about potential silting and surface runoff (Patzold et al. 2008). Hence they are indices for the risk of soil loss and soil erosion.

The porosities (*P*-values) of the 100 cm^3 soil cores were determined in laboratory with a gas pycnometer (from Eijkelkamp). The corresponding field capacities of the soil cores were determined gravimetrically by water releasing and converted by the corresponding *P*-values in percentages of the total volumes (DIN 18121-1, DIN 19683-13 and DIN 19683-4).

The soil pH values were measured in a 0.01M $CaCl_2$ suspension at a soil-to-solution ratio of 1:2 with a potentiometer in laboratory and according to DIN ISO 10 390.

RESULTS

Relevant alphanumeric characteristics of the observed locations are summarized in Table 1 (for XG-areas) and Table 2 (for RF-areas). The species list of the (forest) botanical mapping according to the Braun-Blanquet scale is reported in Table 3.

The soil profiles are depicted in Fig. 2. All soil profiles show high contents of coarse fragments. The soil textures are mostly dominated by coarse-grained and fine-grained substrates. A further similarity is the weak development on unconsolidated mineral materials. All profiles are without clear horizonations or any significant profile development. The remarkable depth of most of the soil profiles (mostly > 150 cm) is anomalous for hillsides in a mountainous terrain. These soil depths are the result of colluvial processes of gravitative movements in the upper area of the slope.

Table 1. Alphanumeric characteristics of location 1–3 in the XG-area

Location	1	2	3
Position coordinates	10°41'2.1" 46°37'39.9"	10°41'5.6" 46°37'45.7"	10°41'53.2" 46°37'46.7"
Altitude (m a.s.l.)	925	1031	1225
Gradient (°)	38	30	33
Exposition	SSW	SSW	SSW
Grid size (m^2)	100	100	100
Size of study area* (ha)	2.1	2.2	1.4
Coverage of shrubs (%)	20	15	20
Coverage of herbs (%)	80	80	70

*sizes of study areas are based on planimetric calculations

Table 2. Alphanumeric characteristics of location 4–6 in the RF-area

Location	4	5	6
Position coordinates	10°40'54.2" 46°37'44.1"	10°40'8.1" 46°37'55.7"	10°40'26.6" 46°38'1.3"
Altitude (m a.s.l.)	954	1123	1230
Gradient (°)	30	35	35
Exposition	SSW	SSW	SE
Grid size (m²)	400	400	400
Size of study area* (ha)	0.9	0.7	0.9
Coverage of trees (%)	20	50	80
Dominating tree species	*Fraxinus ornus* *Pinus nigra* *Pinus sylvestris*	*Larix decidua* *Pinus nigra* *Pinus sylvestris*	*Pinus nigra*
Age of forest stand (a)	60	60	60
Tree height (m)	12	15–20	10
Coverage of shrubs (%)	1–5	5	< 5
Coverage of herbs (%)	65	40	25

*sizes of study areas are based on planimetric calculations

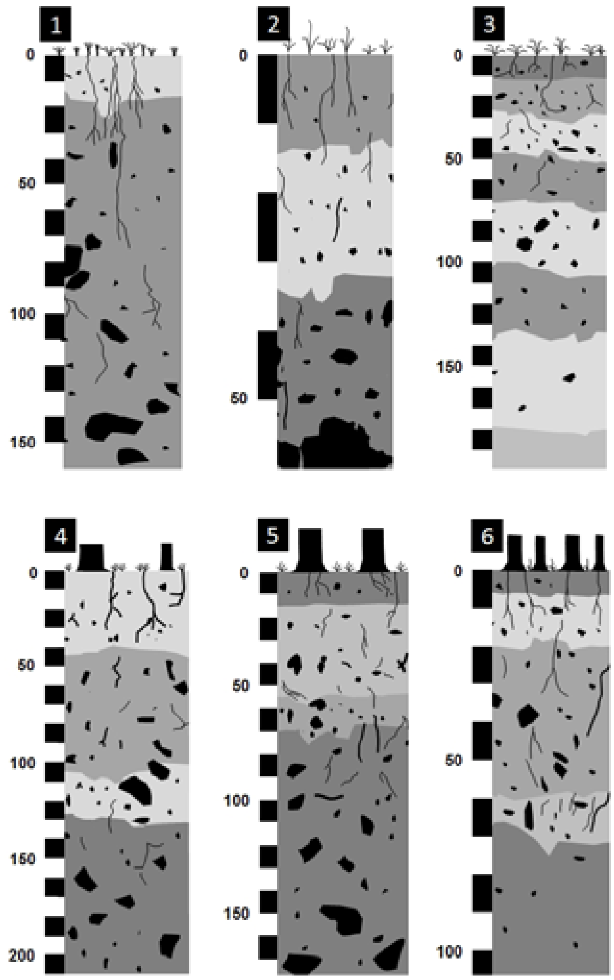

Fig. 2. Soil profiles of the locations

In literature soils with podzolic properties are described for the wooded areas on the southwardly exposed hillsides (Otto 1974; Feichter, Staffler 1996; Feichter 2007b). This allegation has been proved false during our own studies in this region. Minor indications of acidification (pH 4.8–5.7) are limited to the topsoil layers there (Fig. 3) and attributed to the retarded decomposition of coniferous litter. These low pH values are of no importance for the present soil chemical development. The median pH values of the whole soil profiles in the RF-area are about pH 6.24 and about pH 6.35 in the XG-area.

The distribution of the pH values in the soil horizons shows obvious differences between each of the locations and a general increase with soil depth. This is a result of the downward leaching and transport of basic cations. But there are no significant differences between the pH values and the rates of debasification of the RF- and XG-locations.

The particle-size grading curve of the topsoils (Fig. 4) does not show any significant differences concerning the particle size distribution of the RF- and XG-areas. The mean values of *Cu* (RF 50.18, XG 80.96) and *So* (RF 4.52, XG 3.48) attest to a principal imperilment of silting and soil compaction with the further consequence of soil erosion.

The mean values of the penetrometer resistances (transect measurements) are in the same range between 0.38 kN·cm^{-2} (RF) and 0.40 kN·cm^{-2} (XG).

Table 3. Species list of the (forest-) botanical mapping according to the Braun-Blanquet scale in the RF and XG-area

Location:	1	2	3	4	5	6
Tree Layer						
Fraxinus ornus	–	–	–	1	–	–
Larix decidua	–	–	–	–	2	–
Pinus nigra	–	–	–	2	3	5
Pinus sylvestris	–	–	–	r	+	–
Shrub Layer						
Berberis vulgaris	–	–	–	+	–	+
Fraxinus ornus	–	–	–	1	–	–
Juniperus communis	1	1	+	+	–	r
Larix decidua	–	–	–	–	r	
Ligustrum vulgare	–	–	–	–	+	1
Lonicera xylosteum	–	–	–	–	+	–
Pinus nigra	–	–	1	–	–	–
Prunus mahaleb	–	–	–	–	+	–
Robinia pseudoacacia	–	–	–	r	–	–
Rosa agrestis	1	+	1	1	1	+
Herb Layer						
Achillea tomentosa	–	–	–	–	+	–
Artemisia campestris	+	–	–	–	–	–
Astragalus onobrychis	–	–	–	+	–	–
Bothriochloa ischaemum	1	1	+	–	–	–
Bromus erectus	–	–	–	–	r	r
Carex humilis	–	–	+	2	1	2
Carex supina	1	–	–	2	3	+
Erysimum rhaeticum	–	–	–	–	r	+
Festuca rupicola	–	1	+	+	+	+
Festuca valesiaca	3	3	2	1	–	+
Fumana procumbens	–	+	–	–	–	–
Hieracium pilosella	+	1	2	–	+	r
Juniperus communis	–	–	–	–	r	–
Larix decidua	–	–	–	–	r	–
Medicago falcata	–	–	–	+	–	–
Oxytropis pilosa	–	–	–	r	–	+
Phleum phleoides	+	–	+	+	–	–
Pinus nigra	–	–	–	r	r	–
Potentilla pusilla	1	+	–	+	–	+
Quercus pubescens	–	–	–	+	+	–
Saponaria ocymoides	–	–	–	1	1	+
Scabiosa columbaria	–	–	–	–	r	–
Sempervivum arachnoideum	+	+	+	–	–	–
Stipa capillata	2	+	2	1	–	–
Verbascum austriacum	–	–	+	–	–	–

r = single individual with small cover (covering less than < 5% of the sample site), + = 2–5 individuals with small cover (covering less than < 5% of the sample site), 1 = 6–50 individuals (covering less than < 5% of the sample site), 2 = covering 5–25% of the sample site, 3 = covering 26–50% of the sample site, 4 = covering 51–75% of the sample site, 5 = covering more than 76% of the sample site, – = no individuals of this species at this location

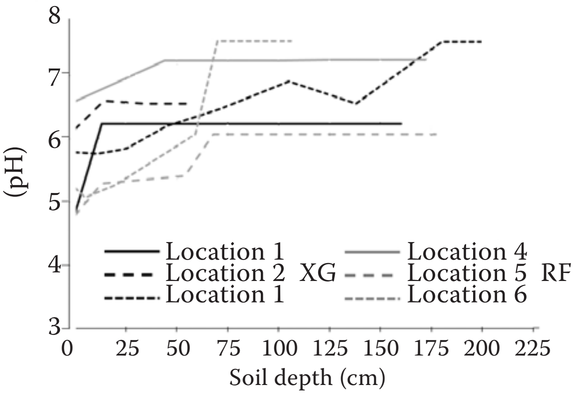

Fig. 3. pH-values in the investigated soils

The dominance of the sand fraction and very small rates of the clay fraction and the high content of coarse rock fragments cause low field water capacities of the soils (Fig. 4).

In the XG-areas these properties are combined with low thermal conductivity and dark coloured A-horizons. The result is a temporary heat build-up (up to +60°C) and a physical (water) stress in the plants. The influence of reforestation on the regional soil water balance is discussed contradictorily in literature.

Otto (1974) stated that monthly water supply in soils of the RF-areas was much lower than in the soils of the XG-areas. Also Florineth (1974) described similar observations on this hillside during climatic field measurements in the drought of 1971. Blum et al. (1986) pointed out that the surface run-off in precipitous woodlands is intensified because of the litter accumulation on the mineral soil surfaces with the consequence of reduced infiltration. However Wilhalm et al. (1995) observed a positive effect of reforestation on the soil water balance.

Our own surveys have shown that (due to the higher rates of interception in the treetops and litter layers) the water supply of soils in the RF-areas is not replenished sufficiently by precipitation. Furthermore the water consumption in RF-areas is much higher than in the XG-areas because of the transpiration processes. In combination with the small rates of precipitation lower moisture penetration of the forest soils must be supposed.

The progress of the measured soil water tensions in Fig. 5 shows the averaged higher soil water tensions at the 10-cm depth (mean values: RF 353 hPa, XG 309 hPa). In the soil depth of 20 cm the mean values of soil water tensions are almost equal (RF 412 hPa, XG 420 hPa). A significantly higher mean value can be noticed at the tensiometer of location 1 at the soil depth of 30 cm with 371 hPa (RF 327 hPa). But in general the soil water

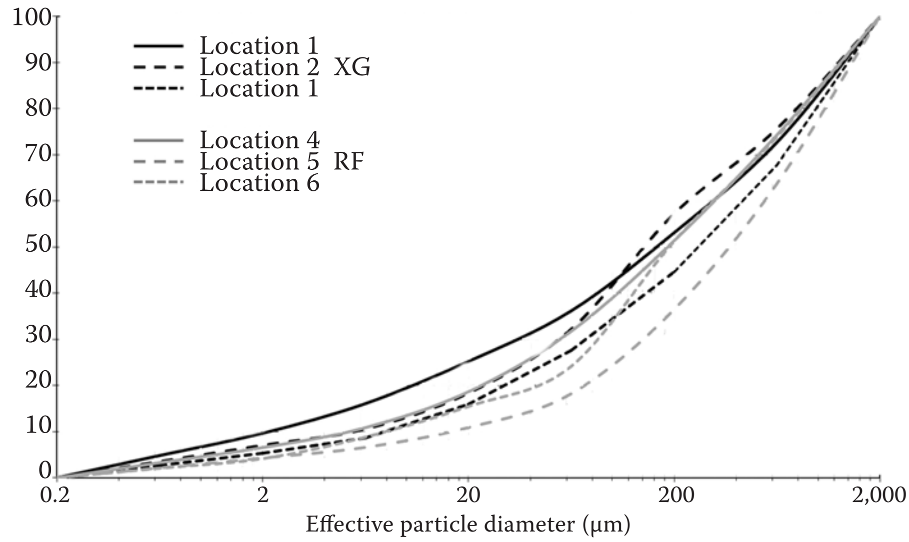

Fig. 4. Particle-size grading curve of the topsoils

tensions present only minor differences. Temporal derivations of less than 100 hPa are ecologically insignificant.

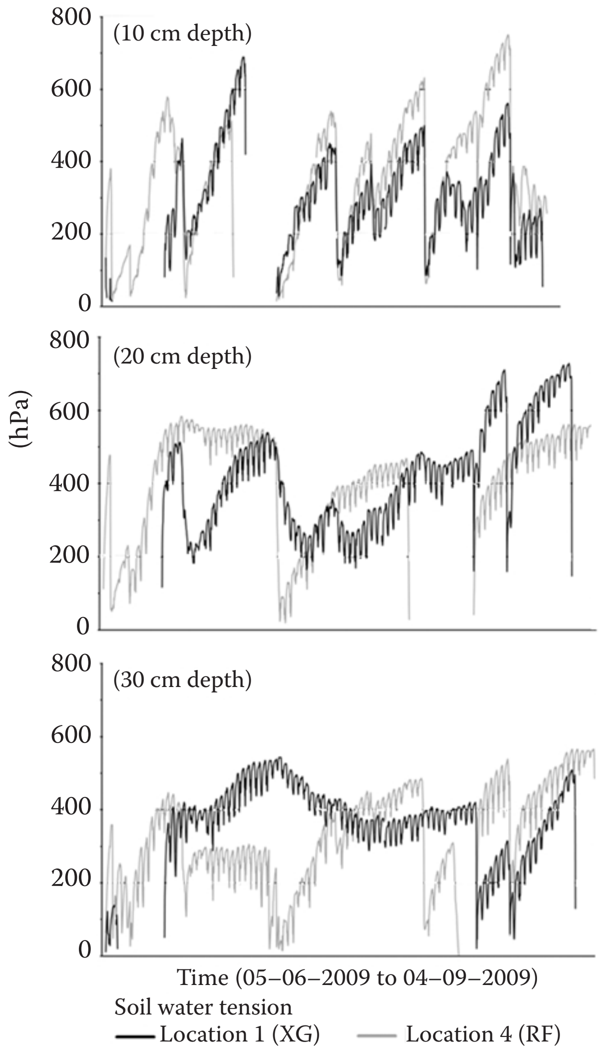

Fig. 5. Progress of soil water tensions between different depths at the observed locations

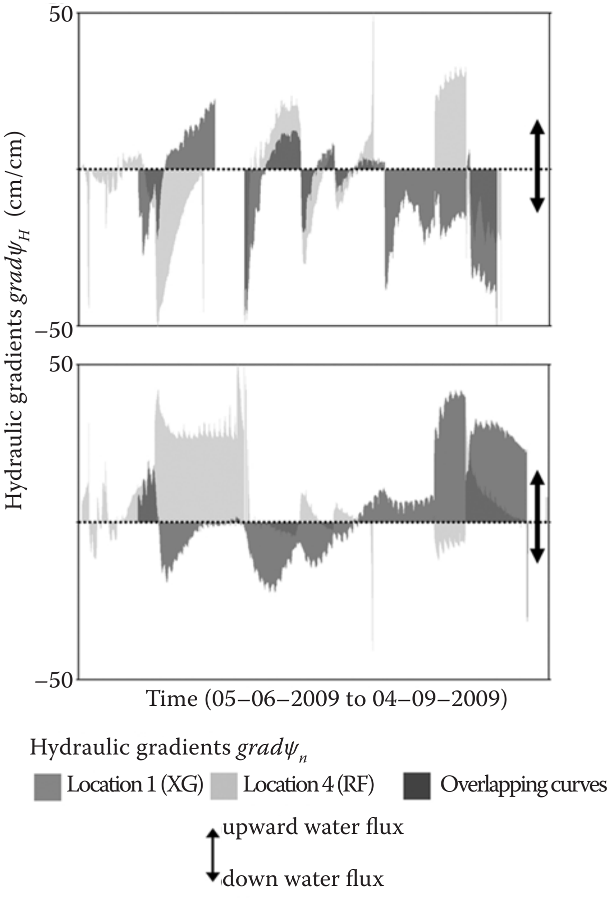

Fig. 6. Progress of hydraulic gradients between different depths at the observed locations

These relations are reflected in the progress of the hydraulic gradients between the different depths in Fig. 6. The directions of water fluxes between 20 cm

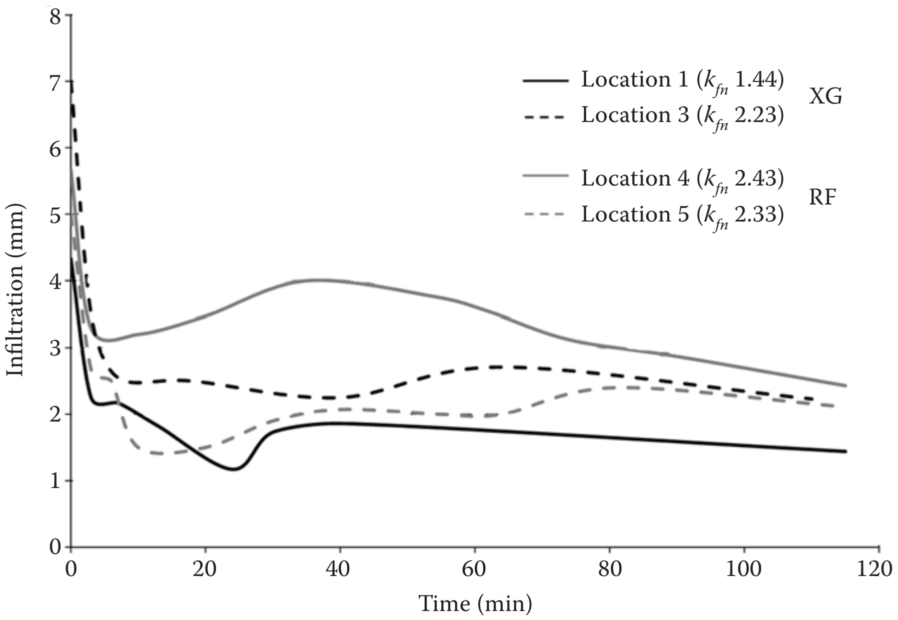

Fig. 7. Rates of ring-infiltration at different locations and kfn-values (mm·min^{-1})

and 10 cm are balanced at both locations (RF with 42% upward, XG with 43% upward). In the sample period the upward water flux between 30 cm and 20 cm dominates at location 4 (RF 72% upward, XG 53% upward) and confirms the observations of Florineth (1974) and Otto (1974).

The infiltration rates show good infiltration conditions at location 1, 3 and 5 (Fig. 7). The high level of curve 4 is connected with pronounced hysteresis. Because of the steepness at location 2 and 6 the measurement of infiltration was impossible there.

The field capacities (Fig. 8) seem to be quite high (± 40%), because they are related to the volumetric soil samples of the fine earth fraction. The coarse pore fraction could not be determined by the use of the 100 cm^3 soil cores in laboratory. Due to the high contents of coarse material in Regosols and the coarse pore fractions corresponding with them

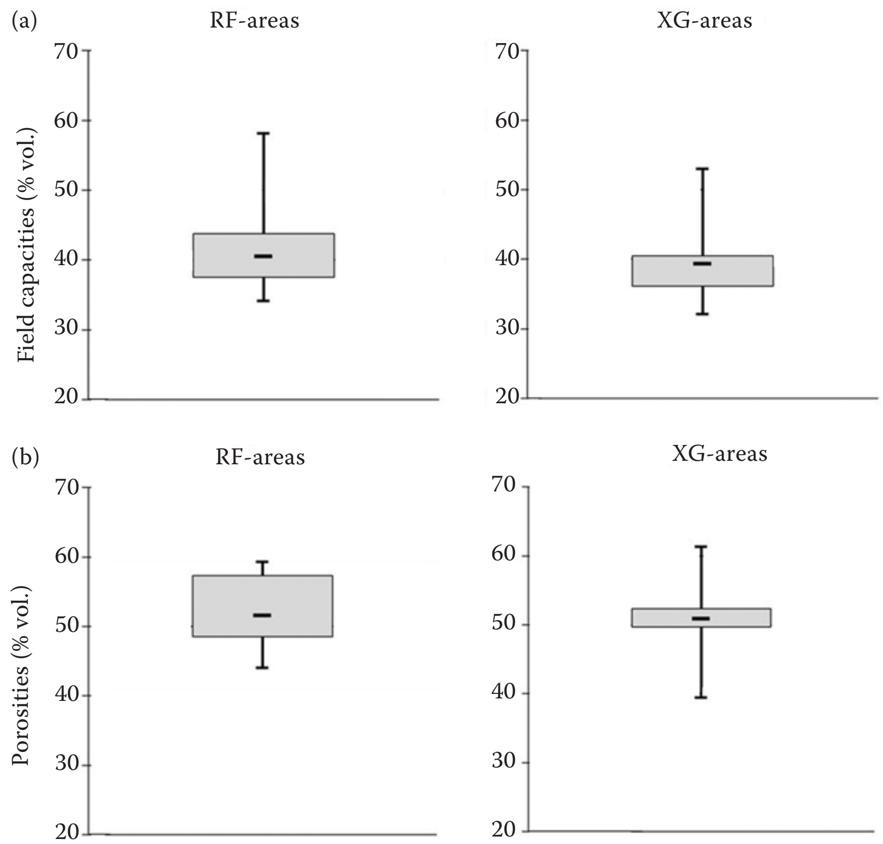

Fig. 8. Field capacities and porosities of the 100 cm^3 soil cores (fine earth fraction only)

the real field capacities must be supposed in the range of 15–25%.

DISCUSSION

The reforestation has caused a significant contrast in the plant population. Corresponding contrasts between the RF- and XG-areas in the soil development have not been detectable so far.

Podzolic processes as described in literature could not be confirmed. There are no significant differences in the pH values of the RF- and XG-areas. Local differences and variations are explained by the parent geological material and not by the forest vegetation. So the minor base saturation at all depths of location 1, 2 and 5 is connected with the metamorphic parent rocks. The higher pH values in the soil of location 4 (Fig. 3) are caused by the calcareous material of the Pleistocene lateral moraine as well as the higher pH values in the deeper horizons of location 3 and 6. Finally the existence of podzolic processes must be questioned because of the regional climatic conditions. The minor soil moisture of the RF-soils prevents pedochemical weathering and chemical soil-forming processes.

The natural shortage of precipitation in the research area has contributed to the marginal development of soils during the past 60 years since the start of reforestation in the RF-areas. Under the given climatic conditions a longer period of time would have been necessary to evolve differences in the development of soils. The more favourable canopy microclimatic conditions in the forests of the RF-areas are not able to compensate this.

The high proportion of sandy fractions and the intensive root penetration cause good infiltration conditions and thus have an inhibitory effect on surface runoff and soil erosion. It is difficult to estimate the influence of climate change like the forecast increase of torrential rain on the soil surface. This depends primarily on the composition of the vegetation suited to climate conditions in future.

CONCLUSIONS

The influence of the soil-forming factor of time (which comprises only a couple of decades) is still too short for the detection of significant differences in soil development. Furthermore, the degrees of soil development have been repeatedly interrupted by processes of soil erosion and colluvial deposition. Ultimately, it must be said that all soils in the study area are characterized by relatively young pedogenesis and therefore no significant differences in the soil development between the RF- and XG-areas can be detected as yet. This assessment contradicts other regional studies on this landscape (Otto 1974; Feichter, Staffler 1996; Feichter 2007b), yet it is plausible because of the short duration, the interruption of soil development by processes of material erosion and deposition, the young history of reforestation and finally because of the dry climatic conditions in this region with a clear reduction of pedochemical weathering on the sun-exposed hillsides.

The general belief in literature that the afforestation in the region under study has a positive influence on the soil water conditions cannot be confirmed. The results show that there are no significant differences in the soil water tensions between the RF- and the XG-areas. At times the soil water tensions in the RF-areas are even higher than in the XG-areas. For the forest vegetation this means a limited supply of soil water. Based on measured data it was possible to calculate the vertical soil water fluxes. The temporarily ascending soil water underscores the existence of soil water stress in both areas during the entire period of measurement.

Contrary to the results of this study it can be expected that there are differences in soil water dynamics between the sites. However, this expectation has not been proved by the used measuring methods. The complex processes of hydrological interaction in the system of soil, plant and atmosphere need a lot of variables beside the properties of soils like quantitative information about the state and phenological variations of canopies, the structure of treetops or leaf area indices. Such interactions must be estimated by numeric simulation models.

The long history of deforestation and the intensive grazing caused the soil compaction with subsequent surface runoff and an intensive linear erosion process with erosion gully as seen in Fig. 1. But currently no processes of soil erosion can be observed. The topsoil layers in the RF-areas are protected by the canopy and the topsoil layers in the XG-areas are fixed by the plaited roots of the steppe vegetation. Especially the closed plant stand of *Festuca valesiaca* stabilizes the soil surface. In the XG-areas the changeover to extensive grazing has had a positive effect on soil and vegetation. The vegetation cover has been supplemented by the expansion of new and digestible species, so that the return and humification of organic matter stabilize the surfaces additionally.

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