Humus dynamics and changes in rooting patterns in windthrow areas

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Abstract
Abrupt changes in site conditions due to windthrow initiate altered dynamics in humus formation, which affect germination, seedling growth and rooting patterns and thus also reforestation. This study examines changes in the upper soil horizons of four long-term observation sites with regard to morphology (humus form), porosity and rooting patterns. The new tall vegetation produces a different type and amount of litter, and the microclimate near the soil surface changes. Biological activity, organic matter turnover and mixing with the mineral fraction are accelerated. Where clearing operations damaged the soil, increased soil density and clogging of pores in the rooting zone impair drainage and aeration, which hinders rooting patterns and retards resettlement by trees, so that reforestation is greatly delayed. Clearing operations should cause as little damage as possible and new stock should be appropriate to the site type.

Keywords: humus dynamics, windthrow, humus form index, bulk density, porosity, rooting patterns, Switzerland

1 Introduction

After windthrow, soils on a site are subjected to rapid changes because of the abrupt alterations in the conditions for humus formation. How are such changes reflected in the soil morphology after a medium-term period and what are their consequences for the seedbed and the growing phase of young trees?

Experience shows that the changes can be detected as early as ten years after the windthrow event through examination of the humus form – defined in terms of the stages of decay of vegetation debris and the depth of the layer in which organic matter is associated with mineral particles (Babel 1971). The development of the soil cover and the luxuriousness of the reestablished shrub layer largely determine the amount and quality of vegetation debris and litter. The absence of the tree layer means that soil temperatures rise, which, provided there is enough moisture, causes more rapid mineralisation of the accumulated organic debris. That in turn results in the release of greater amounts of plant nutrients, which then influence the development of the vegetation to a greater or lesser extent.

The changes in rooting patterns in the subsoil following the fracture or windthrow of trees have serious consequences for the pore system in the rooting zone, depending on the stage of soil development and the stability of its structure (Polomski and Kuhn 1998). Comparison with undamaged reference sites shows that the density of the pore network changes markedly after windthrow.

The aim of this study was to identify such changes by comparing the soil pore volume shortly after a windthrow event with that found nine years later. The pore volume directly influences the water percolation and, depending on the weather, the aeration situation in the rooting zone.

In windthrow areas, water is no longer removed from the soil by the trees so that the degree of soil-water saturation increases and the aeration of the root zone is impaired. The re-establishment of the root network takes place in stages and only begins with the growth of a subsequent stand. Insufficient aeration hinders the re-colonisation of the potential root zone (JEHL 2001).

The central questions of this study are thus: What changes do the development of the vegetation after windthrow and the alterations in the micro-climate near the soil surface cause on the soil surface, in the topsoil and in the root zone; and what are the consequences of these changes for reforestation in windthrow areas?

2 Methods and site conditions

2.1 Methods

After the storm Vivian, soil investigations were conducted in 1991/92 and nine years later, in 2000/01 (for study design see WOHLGEMUTH *et al.* 1995) at the four long-term observation windthrow sites Pfäfers (P), Schwanden (S), Disentis (D) and Zweisimmen (Z). The investigations comprised the classification of reference profiles representative of selected site types (P 6, S 11, D 13, Z 6) and profiles supplemented by soil coring taken from long-term observation sites (P 25 profiles + coring; S 28 profiles + coring; D 31 + coring; Z 35 + coring).

The soils were described in terms of form of humus, soil type (stage of weathering), hydromorphic properties, acidity, density/porosity, granulation of the fine soil fraction, skeletal content, lime limit, thickness of the main and lateral root zones and the density of rooting.

Topsoil

Typical forms of humus (AK SK 1996):

- mull: vegetation debris is decomposed by intense biological activity and complete mixing in the mineral soil.
- moder: biological activity is reduced. Decomposition of vegetation debris is slower and incomplete, so that a fermentation horizon develops.
- raw humus (mor): biological activity is low, decomposition hindered. The annual layers of litter deposits are distinct. The horizon where mixing with the mineral soil occurs is poorly structured and thin.
- transitions: moder-like mull, mull-like moder, raw humus-like moder.

Humus

The humus form was classified according to the humus form index of MÖLLER (1981) and the C/N ratio in the upper mineral soil horizon of the reference and long-term profiles together with corings.

The humus form index is the quotient of the depth of the mixing layer (Ah horizon) and the thickness of the accumulated litter. The more biologically active the humus form, the higher the humus form index (index value for mull = 1).

Humus form index

Ah / F+H+Ah	(thickness in cm)
Ah	topsoil horizon enriched with humus
F	fermentation horizon (partly decomposed vegetation debris)
H	humus horizon (largely decomposed vegetation debris)

Root zone

Wherever possible, the total volume of pores was determined as the density (volume per weight and volume of material per weight) for each horizon in the reference profiles.

Porosity x 100 = volume of pores in percent
e.g. if porosity E = 0.5 x 100 pore volume = 50%v

The root network was differentiated into fine roots (Ø <2 mm), coarse roots (Ø 2–20 mm) and major roots (Ø >20 mm) and examined on the profile walls:

- at intervals of 10–20 cm over a 10 x 10 cm grid for fine and coarse roots;
- at intervals of 50 cm over a 50 x 50 cm grid for major roots.

The density of the network (no. of roots per unit area) was classified on a five-point scale (no roots to high density). Reference values were those under neighbouring, undamaged tree stands with comparable site conditions.

For selected long-term profiles with little or no skeletal material, the water content of each horizon was determined by means of TDR probes (ROTH *et al.* 1990), always under similar weather conditions.

2.2 Soils and humus types on the four windthrow sites

The locations and detailed descriptions of the four study sites are given in SCHÖNENBERGER (this issue). Each windthrow area had its own characteristics of soil formation. An overview of humus formation and soil development (FAO 1988) is given in Figure 1.

At Pfäfers most of the humus forms are biologically active but due to the high proportion of conifers in the old stand (before the windthrow) there is a transition towards moder, with horizons containing the deposited organic debris of several years together mixed to a shallow depth. In some places, the weathered soils (Cambisols and Luvisols) have deep potential root zones which can only be fully exploited by mixed-aged stands with a near-to-nature species composition.

At Schwanden the active forms of humus occured in well-drained to wet areas of the site types originally demarcated, whereas moder and raw humus were more likely to be found under dry conditions – albeit also combined with original stands which had a relatively high proportion of conifers and were almost even-aged (Fig. 2).

At Disentis the whole spectrum of humus forms was found. Raw humus and types of moder occurred in combination with developing Podzols.

At Zweisimmen, the forms of humus were closely related to the original site type. Moder-raw humus forms were found on slope-screes, while the humus form on Cambisols-Regosols was frequently mull.

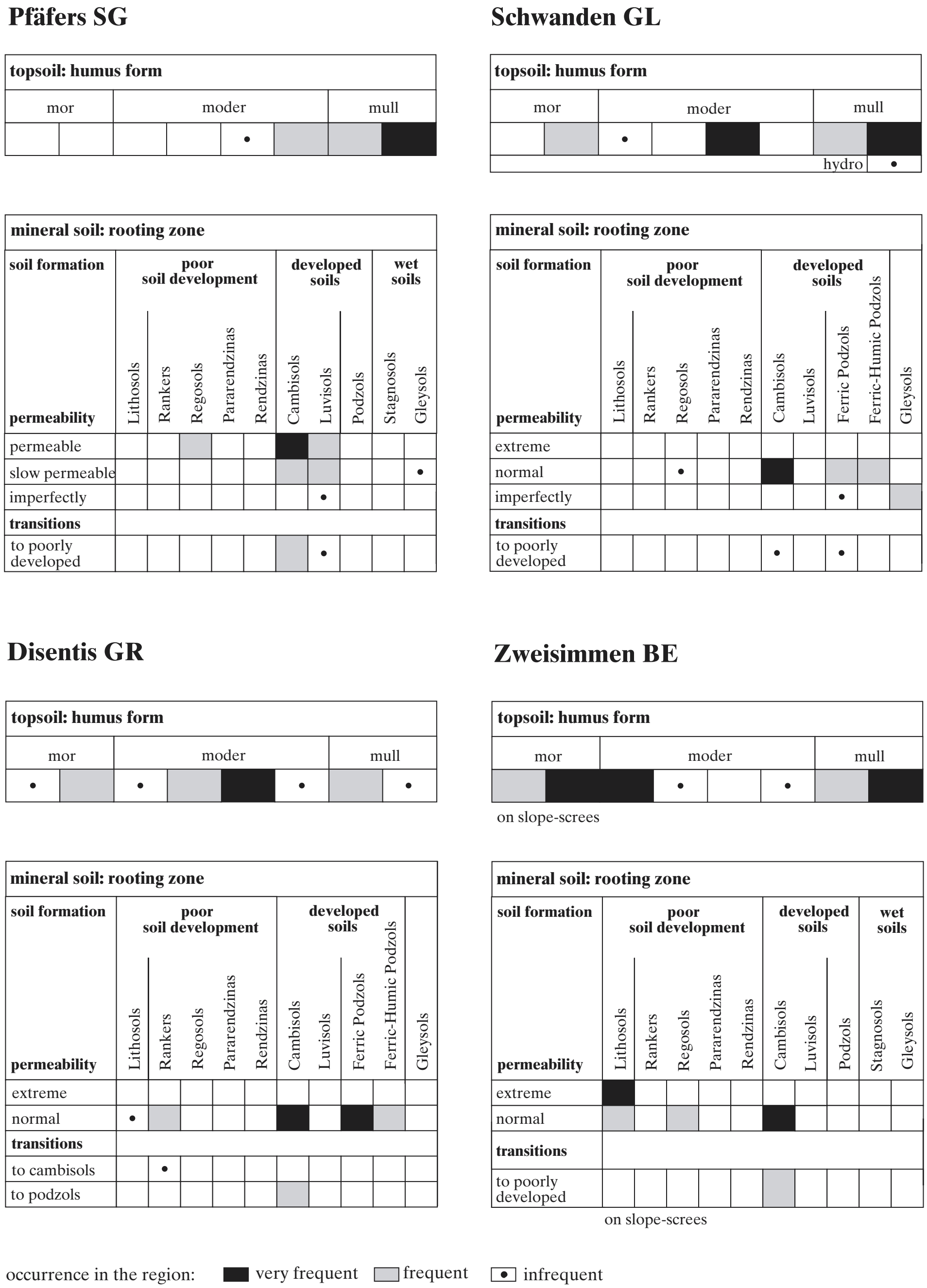


Fig. 1. Humus formation and soil development on the four windthrow sites Pfäfers, Schwanden, Disentis and Zweisimmen.

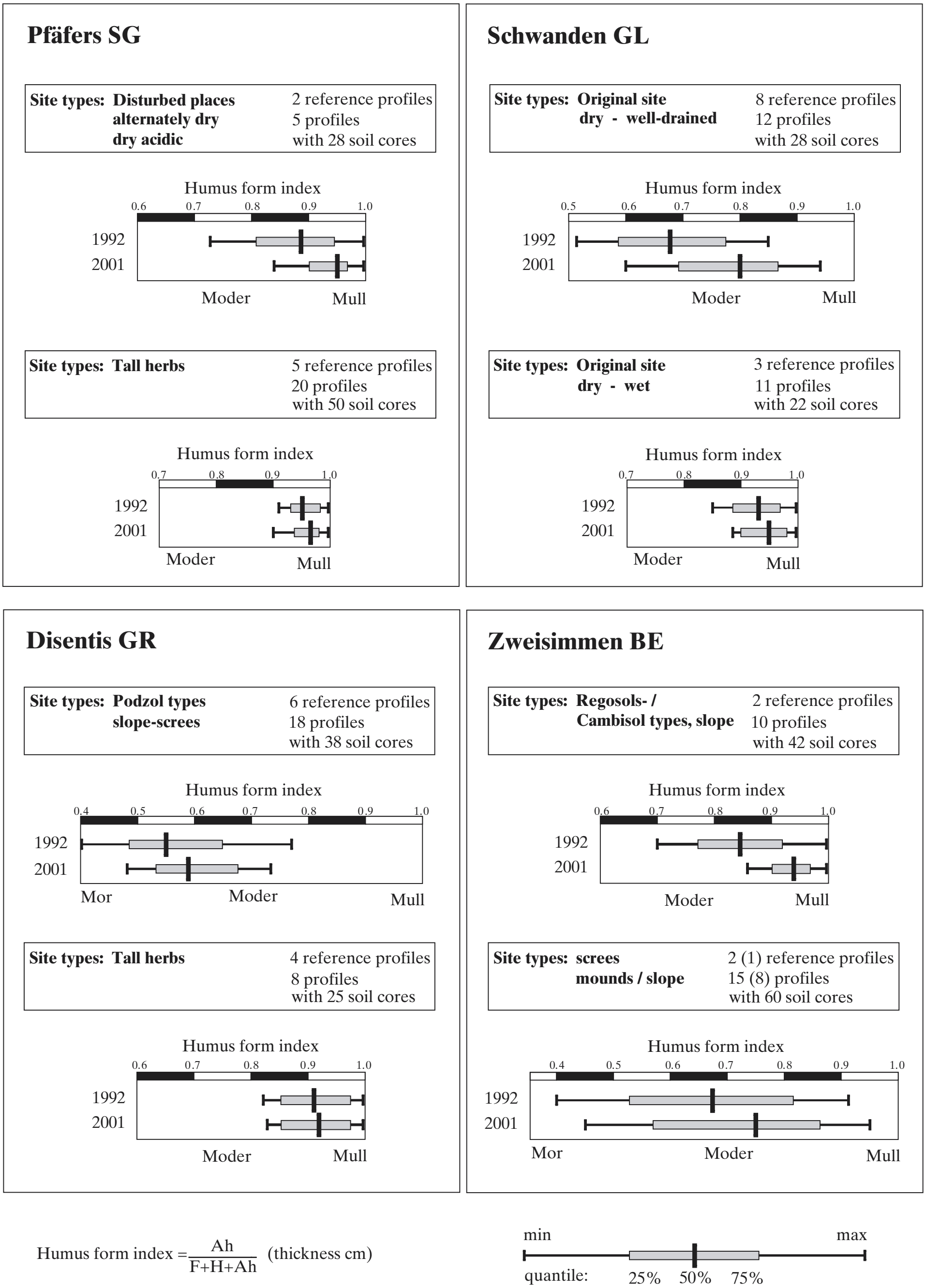


Fig. 2. Humus dynamics on the four windthrow sites Pfäfers, Schwanden, Disentis and Zweisimmen.

3 Results

3.1 Changes in the topsoil

Morphological changes in the topsoil were assessed on the basis of the humus form index (Fig. 2). The second survey showed that on all four sites humus form development had become more active (FISCHER 1998). The higher humus form indices revealed that in 2001 the horizons of deposited litter were thinner. In 1992 the influence of the old stands, mainly conifers, was evident, but by the time of the second survey the effect of the altered site conditions on the decomposition of vegetation debris had become evident.

The greatest changes were found in the humus form moder at the study sites Schwanden (site type: dry–well-drained) and Zweisimmen (site type: Regosols–Cambisols). At Pfäfers (site type: alternately dry and dry acidic) the organic deposition horizon had almost totally disappeared. At Disentis the formation of raw humus in combination with podzolisation was slightly but discernibly evident.

Active humus forms with an index of >0.9 in combination with tall forb communities (Pfäfers and Disentis) also showed only slight changes due to the exposure of the topsoil by the windthrow. Although the trees were no longer present, the practically closed cover of tall forbs had an homogenising influence on the microclimate near the soil surface.

The intensity of mixing with the fine mineral fraction was markedly improved. By 2001, areas where the blending had been inhibited, denoted by clear dark to blackish colours occurring directly under the organic deposition horizon at Schwanden, Disentis (exception: Podzol types) and Zweisimmen (exception: slope-screes), had totally disappeared.

The soil-water contents, measured after average precipitation events, at a depth of 30 cm for purposes of comparison, were higher because of the lack of cover and interception by trees. On the other hand, this exposure resulted in higher temperatures near the soil surface, and the differences between the high and low values were more clearly marked. This resulted in very dry or very moist phases, which positively influenced the activity of soil organisms.

Where, in the absence of a closed vegetation cover, mineral horizons lie on the surface, as was the case in the first few years after the storm especially on cleared areas at Schwanden and Pfäfers, rapid drying down to a depth of 35 cm was observed, especially along shrinkage cracks. During heavy precipitation, the terrain was such that the water was rapidly channelled down to even deeper levels.

3.2 Changes in the rooting zone

Pore structure

Measurements of density in each horizon of selected reference and long-term profiles revealed that the bulk density of the fine earth had increased and the porosity computed from it had decreased over the nine-year interval (Fig. 3).

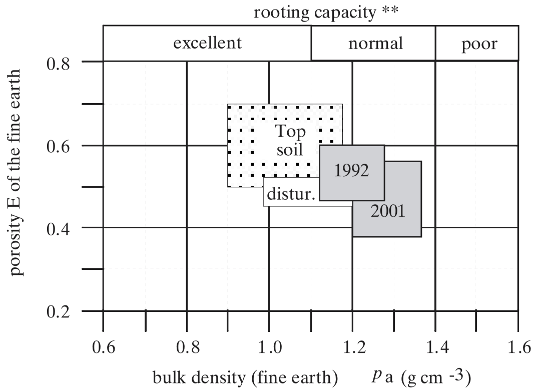
The density measurements in the topsoil produced a very heterogeneous picture, so that it was only possible to compare conditions after the storm and nine years later to a limited extent.

Surface scars (Pfäfers) mainly resulted from dragging timber over the ground during clearing work. The consequence was considerable soil compaction, as higher densities (mean 0.2 g cm^{-3}) already showed in 1992. Soil structure was disturbed in some places and the percolation pattern changed. The recolonisation of such areas by herbs and natural tree regeneration takes place only very slowly and was still incomplete nine years later. It can be concluded that the pore discontinuity due to soil disturbance had not been overcome by root infiltration within that period. Damaged pore systems need longer to recover. In places

Pfäfers SG

Site type: dry - acidic disturbed type — 1 reference profile, 3 profiles (disturbed)

porosity $E = 1 - \frac{p\,a \text{ (bulk density)}}{p\,r \text{ (density)}}$ E• 100 = pore volume in %v



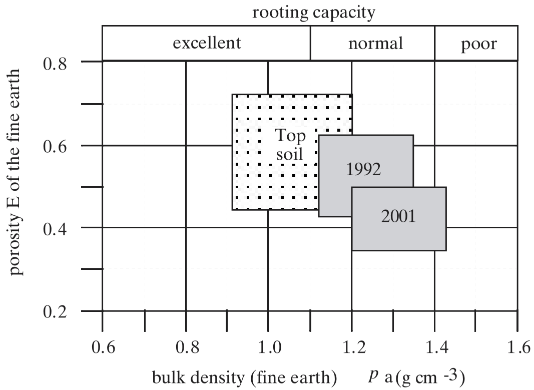
* topsoil: disturbed by clearing operations ** suitability of soil for root growth

	topsoil n = 9	disturbed* n = 9	rooting zone 1992 n = 12	rooting zone 2001 n = 12	subsoil n = 3
E	**0.65/0.55**	**0.54/0.45**	**0.60/0.47**	**0.57/ 0.38**	**0.35/0.32**
density (g cm^{-3})	**0.9/1.18**	**0.99/1.34**	**1.15/1.28**	**1.20/1.38**	**1.39/1.43**

Schwanden GL

Site type: dry - well-drained original site — 6 reference profiles

porosity $E = 1 - \frac{p\,a \text{ (bulk density)}}{p\,r \text{ (density)}}$ E• 100 = pore volume in %v



	topsoil n = 15	rooting zone 1992 n = 18	rooting zone 2001 n = 18	subsoil n = 12
E	**0.72/0.43**	**0.62/0.42**	**0.50/0.55**	**0.38/0.30**
density (g cm^{-3})	**0.81/1.20**	**1.11/1.33**	**1.23/1.42**	**1.41/1.51**

Fig. 3. Changes in the root infiltration zone (density and porosity) on the sites Pfäfers and Schwanden.

it was only possible to register shrinkage cracks, which acted as macropores and rapidly conducted surface water to deeper levels (up to 35 cm), but also led to rapid drying of the topsoil in dry weather.

In the rooting zone pore volumes changed markedly during the nine-year period. At Pfäfers the densities did not reach the critical range of >1.4 g cm^{-3}, but in some places at Schwanden (site type: dry–well-drained to perfectly drained), they exceeded the critical range, which means a purely physical obstacle for future root penetration (KÖSTLER *et al.* 1968).

Further, water content measurements after heavy rainfall indicated high degrees of water saturation, with possibly impaired aeration. On sites tending towards saturation the sudden cessation of water removal by trees led to a lengthening of the moist phases with periodic anaerobic conditions in the root zone. Compaction due to sinkage occurred (HILDEBRAND 1987), resulting in anaerobic conditions that block the biological processes of structure formation.

Displacement of fine particles is known to be a natural soil-formation process in Luvisol types. In the present study, the danger of silting-up of the pore spaces was found to increase with heavy rainfall, especially in soils with a labile structure. At Schwanden, in particular, silt cutans were found along the larger pores and cracks on sites with Cambisol types.

Intensity of root infiltration

The penetration of the soil by roots was determined on selected site types at Pfäfers, Schwanden and Disentis (Fig. 4).

At Pfäfers, two site types (dry-acidic and tall forbs) were investigated. In 1992 the situation reflected, on the one hand, the different soil structures (Luvisols and poorly developed Cambisols) and the other the multi-storeyed to single-storeyed structure of the original stand. The intensity of root infiltration in the deeper part of the clay enrichment horizon of the Luvisols between 40 cm and 80 cm had markedly increased. In 2000, the different conditions for regeneration on the two site types were evident. The new fine roots of the tall forbs were dominant in the active topsoil of the poorly weathered Cambisols.

At Schwanden it was evident how deeply the root network of the original stand had penetrated the soil (site type: dry–well-drained, mainly stocked with spruce, single-storeyed, 78 years old at the time of the windthrow). In 2001 renewed root infiltration was mainly due to fine roots forming near the soil surface.

At Disentis in 1992 on the Podzols with raw humus the root network in the litter deposit horizons was dense and comprised all classes of roots. In 2000/01 the topmost mineral earth horizons had been leached, were poor in nutrients and were only infiltrated by roots very close to the surface. As the toppling of the trees during the storm tore out practically the whole root zone, i.e. the litter deposit horizons over quite large areas, comparisons were difficult. Regeneration on damaged horizons on pure mineral topsoil was only weak, so that renewed root infiltration was very slow.

4 Conclusions and discussion

Improved, more biologically active humus forms in topsoil

The qualitative and quantitative changes in the litter input due to the windthrow, together with the completely changed conditions of heat and water in the micro-climate near the soil surface, resulted in a generally accelerated biological activity of the humus on all site types.

The nine-year period under the changed conditions brought about considerable increase in the turnover of accumulated organic deposits in the transitional forms between moder

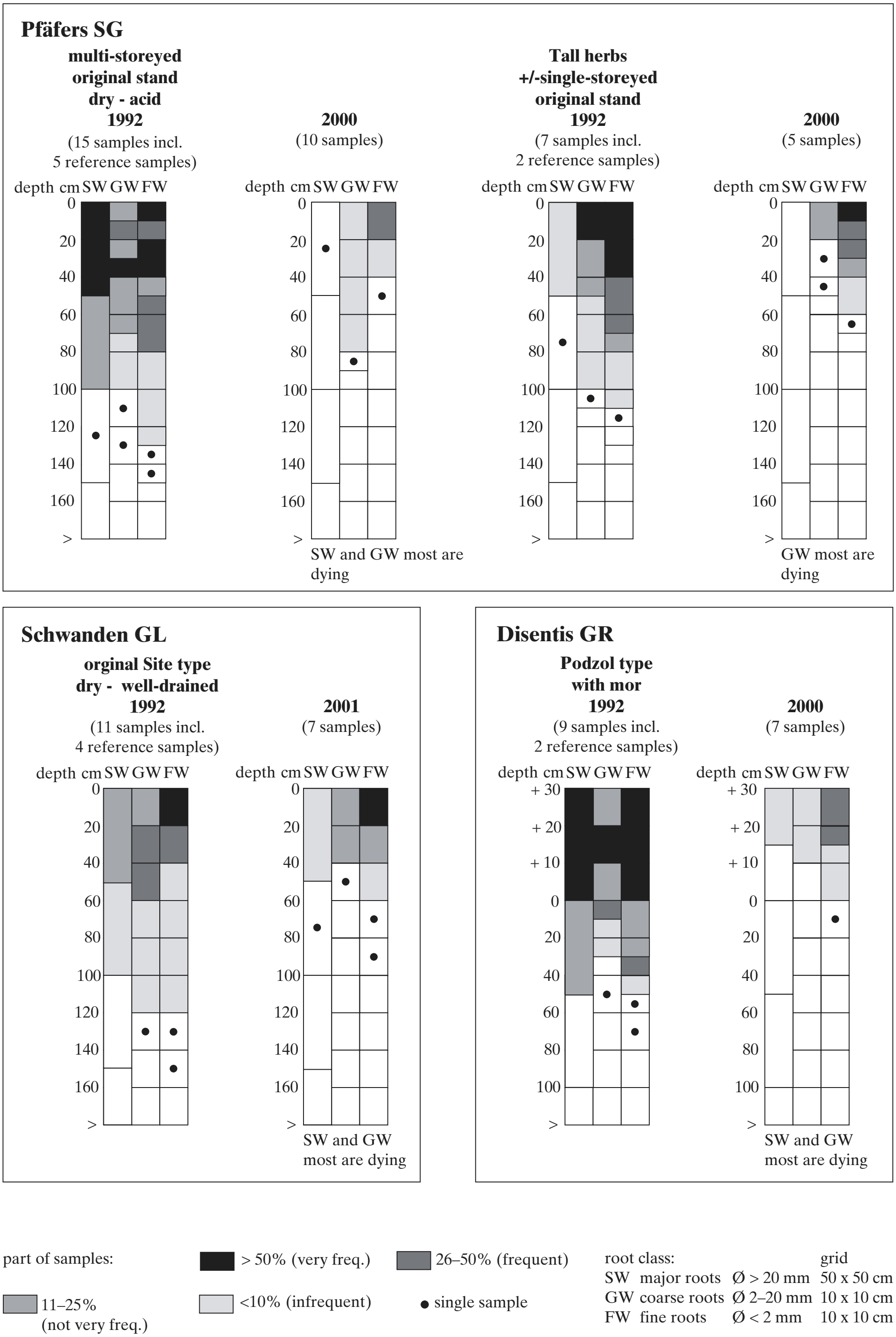


Fig. 4. Intensity of root infiltration on selected site types at Pfäfers, Schwanden and Disentis.

and mull. Inactive nutrients were transformed and became available to plants. Under the canopy of the homogenising tall forb layer, mixing with the mineral soil clearly improved and incipient structural development was found. In some places, damage to the soil surface through clearing operations led to increased soil density, resulting in local disturbances of the structure and impaired seepage (Pfäfers and Schwanden). In poorly developed, coarsely grained soil (e.g. Disentis) with low water storage capacity and normal permeability, these negative changes in the water balance parameters were less important.

Changes in the rooting zone

Decreased densities clearly affected the pore system, leading to impaired aeration. Translocation of fine particles within the pores of root areas led to clogging of the pore system. The greater the development of the soil, the greater the danger that, in the structurally labile range (e.g. where the soil surface was damaged or the vegetation cover was not closed), the fine pores in particular became blocked, to the detriment of the water percolation. With the additional lack of transpiration (in the absence of removal by roots) problems in aeration developed (Pfäfers and Schwanden).

The potential root area needs to be opened up anew by coarse and major roots, which will require stocking appropriate to the site type and, above all, time. The fine root zone near the soil surface, where fine roots had infiltrated the soil, showed clear signs of resettlement. Stocking appropriate to the site and stand structure will play an important role in the exploitation of the available root area and thus also in the stability of the future stand.

It should be emphasised, therefore, that clearing operations on windthrow areas must preserve the soil as much as possible. Where the pore system is disturbed, forest regeneration requires longer than elsewhere. Damage to the topsoil leads to negative changes in the soil-water parameters throughout the entire root area, for instance, due to pore clogging. If there are then periods of impaired aeration due to unfavourable weather, the resettlement of the soil by roots is hindered and may be retarded for years.

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