4.1 Depth of the Effective Root Zone

The parameter effective rooting depth, or the depth of the effective root zone, is defined as the potential depth down to which, in dry years, plant roots can take up the maximum amount of plant-available water from the soil. The zone between the surface and the effective rooting depth is the interval from which plants obtain their supply of water and nutrients. It is the main factor governing which type of crops are suitable, how they grow, the evapotranspiration, and the crop yield. The effective rooting depth is therefore used as input data in models used to estimate the evaporation loss per unit area.

During compilation of Map 4.1, the effective rooting depth was determined primarily from soil-physical properties neglecting the effects of nutrient deficiency or low pH, which also restrict root growth.

Calculation of the effective rooting depth is based on the moisture distribution in the soil profile at the end of the growing period in markedly dry years at sites with a low water table. The effective rooting depth is taken as the depth (Fig. 1) at which the difference between the moisture content and the permanent wilting point (dotted area) is the same as that between the in-situ field capacity and the moisture content (shaded area).

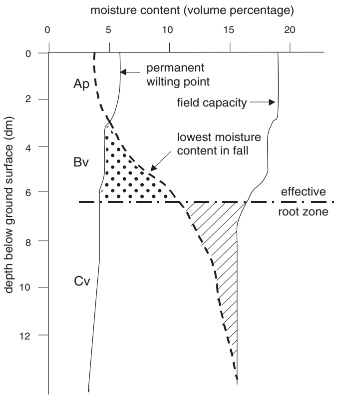

Fig. 1 **Example for the determination of the depth of the effective root zone using the parameters field capacity, permanent wilting point und the water content of a Eutric Cambisol from sandy sediments in the fall of a dry year** (from Renger & Strebel 1980)

The exact determination of a soil-hydrological parameter such as the effective rooting depth requires time-consuming and expensive field measurements at numerous sites. However, pedo-transfer functions are a possible alternative. These permit the effective rooting depth to be estimated from comparatively easily determined soil properties via empirical relationships. It is essential to determine the effective rooting depth specifically as a function of the type of plant at the site. Renger & Strebel (1980) compiled a table for root crops, cereals and pastures that permits the effective rooting depth to be derived from soil texture class and bulk density. This table was later slightly modified and expanded and then incorporated, in a form designed for cereal crops, in the 4th edition of the Bodenkundliche Kartieranleitung (German soil mapping guidelines, AG Boden 1994).
A similar method has been developed for forest sites by Lehnhardt & Brechtel (1980). The method is somewhat simplified with respect to soil conditions, but permits subdivision on the basis of up to seven tree types and three age classes. If detailed information is not available on the tree stands, then it is suggested that the table in DVWK (1996) is used, which provides still further simplification.

Map Structures

On the basis of soil texture class and bulk density, the best conditions for deep rooting occur in the silty and clayey soils of the loess areas, Tertiary hilly areas and flood plains. Loam soils and especially sandy soils such as are developed in the Pleistocene lowlands and are also characteristic of the low mountain and hilly lands show a shallower effective rooting depth. The fen and raised-bog peatlands of the Pleistocene lowlands also show a shallow effective rooting depth, which is restricted by the shallow depth of the water table. In hilly country and uplands (Mittelgebirge) and especially in the Alps, the shallow depth of the bedrock and the large amount of periglacial rock debris tend to reduce the effective rooting depth.

In Central Europe, which has been inhabited for thousands of years, the most fertile land is normally used for crops and the shallow soils of the central German uplands are normally forested. Considering the distribution of the main types of land-use, the soils of the coastal region and peatlands are seen to have the largest share (80 % by area) of agricultural land, of which the largest proportion is grassland. In the loess areas, where the proportion of agricultural land is nearly as high, about 76 %, arable land is predominant. On the valley bottoms and lowlands, which consist of almost 69 % of agricultural land, arable land is again predominant. Similarly, about 65 % of the undulating and hilly lowlands comprise agricultural land, and about 30 % is forest. The soils of the central German uplands and other mountainous areas support almost equal proportions of agriculture and forestry, 49 % and 46 %, respectively, much of the agricultural land being grassland. The soils of the high mountains support mostly forest (83 % of the area) and the agricultural land, which is chiefly grassland, is restricted to 6 % of the area.

The highest values of the effective rooting depth are recorded for the agricultural soils in the loess and sandy loess areas of central Germany, the Tertiary hilly areas in the Alpine foreland, on the flood plains of large valleys and the coastal belt of Holocene calcareous marshland. Forest stands, including deep-rooting types that can use the deepest plant-available water, are only present in small amounts in these areas. Thus, areas with high values for the effective rooting depth beneath forest comprise a relatively small proportion of the area of the Federal Republic of Germany. One finds low and very low values of the effective rooting depth for agricultural land mostly on arable land on light sandy soils in Lower Pleistocene areas and in the peatlands of Niedersachsen (Lower Saxony) and Mecklenburg-Vorpommern (Mecklenburg Western Pomerania), which are mostly grassland. However, in the central German uplands little arable land with shallow effective rooting depth is found because the shallow soils of this region currently support forest. The forest soils of the Alps, of the Rheinisches Schiefergebirge and of the Harz Mountains are characterised by shallow to very shallow rooting depths.

Map 4.1 is based on a soil map that is subdivided with respect to land use, since the typical soils of a given soil association under agriculture and forestry are quite clearly different. In this land-use soil map, one soil profile representative of agricultural land and one of forest land were selected for each map unit in the legend, paying special attention to soil properties relevant to the effective rooting depth, such as content of rock fragments and depth of bedrock. The land-use data were obtained from the "CORINE Land Cover" (Statistisches Bundesamt 1997), a digital map derived from satellite images. As a result of the high information density, it was necessary to generalise the land-use data for use on 1 : 2,000,000 maps. The 36 land-use types of Germany visible on the satellite images are arranged in 15 groups in the CORINE Land Cover (different from the hydrological classification of land use, Map 1.4) and were then further classified into the following land-use categories:

1 Built-up areas (including industrial and commercial areas, and roads and railways),
2 Mine areas (including waste disposal sites),
3 Agricultural areas (arable land, plantations and pastures),
4 Forest and quasi-virgin land (including natural pasture, heath and peatland heath),
5 Areas that have little or no vegetation (beaches, dunes, rocky areas, and permanently snow-covered areas),
6 Wetlands (swamps, marshes, mires, and salt meadows),
7 Lakes, rivers, reservoirs, and canals,
8 Tidal flats.

The generalisation of the land-use data concentrated on the assignment of areas smaller than the smallest size that can be represented on a map, i.e. 16 km² (= 4 mm² on the map), to neighbouring areas of related land use. In this way, the original land-use pattern was largely retained. Modifications are confined to small areas and the changes in land-use classification of these areas are minimal. The land-use map produced by this process of generalisation was then superimposed on Map 1.3 to produce a 1 : 2,000,000 soil map subdivided according to land-use.

Tables showing land-use-specific algorithms were used to determine the effective rooting depth for the areas of agricultural and forestry land produced as above. The resulting effective rooting depths are subdivided using land-use specific classes since the rooting depths are different for agricultural crops and forest trees, even though the sites have otherwise similar soil properties. Subdivision into different classes is done on the basis of the frequency distribution of the values for all map units in the legend. The other land-use classes are given on the map but with no rooting-depth information.

This procedure subdivides the map firstly according to soil conditions and secondly according to dominant land-use type. The effective rooting depth in arable and grassland soils is shown by a colour scale from pale yellow to dark brown, and in forest soil from pale to dark green, indicating increasing depth from very shallow to very deep.

Determination of the effective rooting depth using pedo-transfer functions

In the case of predominantly agricultural land, the table mentioned above, in the German soil mapping guidelines (AG Boden 1994) was used, so that Map 4.1 provides us with the effective rooting depth in these areas when used for annual agricultural crops.
An initial value as a function of the soil texture class (Fig. 2) and dry bulk density can be read off from Table 1. In addition the following soil properties were taken into consideration, and they lead to positive or negative corrections:

- The effective root zone is bounded at depth by unweathered bedrock,
- in soils in which the water table is shallow, the effective rooting depth corresponds to that of the upper boundary of the Gr horizon, which is approximately the same as the mean lowest depth of the water table,
- in Podsols, the degree of compaction of the Bh, Bhs, Bs or Bsh horizon possibly sets a limit to the effective rooting depth,
- in flood-plain soils, colluvium and plaggenesch, 10 cm is added to the effective rooting depth if the typical colluvial or esch horizon is deeper than the effective rooting depth in Table 1.

For determination of the effective rooting depth in the case of areas that are predominantly forest, the procedure recommended by the soil mapping guidelines was followed, i.e. the value for arable land was obtained from Table 1 and then increased by 20 %. The effective rooting depth was only increased when the effective root zone was not bounded by bedrock, groundwater or a Podsol (ortstein) zone enriched in sesquioxides.

Table 1 **Mean depth of the effective root zone for homogeneous soils in dependance of soil texture class and class of bulk density given for arable land**

soil texture class	class of bulk density		
	ϱt1 - ϱt2	ϱt3	ϱt4 - ϱt5
Ss	8	6	6
Sl2	9	7	6
Sl3	10	8	7
Sl4	13	9	8
Slu	13	9	8
St2	10	8	7
St3	13	9	8
Su2	9	7	6
Su3	9	7	6
Su4	9	7	6
Uu	13	10	8
Us	13	10	8
Uls	14	11	9
Ut2	14	11	9
Ut3	14	11	9
Ut4	14	11	9
Lu	14	10	8
Ls2	13	10	8
Ls3	13	11	9
Ls4	13	11	9
Lts	13	11	9
Lt2	13	11	9
Lt3	13	11	9
Tt	13	10	8
Tl	13	10	8
Ts2	13	10	8
Ts3	13	10	8
Ts4	13	10	8
Tu2	13	10	8
Tu3	13	10	9
Tu4	14	11	9

ϱt-classes 1+2 < 1,45 g/cm³
ϱt-classes 3 < 1,45 - 1,65 g/cm³
ϱt-classes 4+5 > 1,65 g/cm³

Practical Information

The content of Map 4.1, as with Map 1.3, is based on the digital data stored in the BGR soil information system (FISBo BGR) (Eckelmann 1995). This applies to the reference soil profiles of the 1 : 1,000,000 Soil Map of Germany (BÜK 1000) stored in the spatial database and the algorithms used to derive the effective rooting depth stored in the method base. A critical assessment of the data content of the BÜK 1000 map according to representativeness criteria has already been given in the explanatory notes on Map 1.3. In individual cases, the values given on the map (derived only from dominant soils) may differ considerably from mean values of the effective rooting depth calculated according to the proportions of the areas occupied by all dominant and associated soils. Map 4.1 only shows two types of land-use and does not distinguish between arable land and grassland, and in the case of land used for forestry no distinction is made to reflect tree type or age of stand. The effective rooting depth values given in Map 4.1 for agricultural land would have to be reduced by an average of 10 to 20 cm for pastures and meadows.

In the case of forest land, Map 4.1 gives the effective rooting depth for deep-rooting trees such as pine, beech and oak with an average stand age of 15 – 45 years. Shallow rooting trees such as birch and spruce would reduce these depths by a factor of about 0.6 – 0.7. In fact, as far as forests are concerned, there is as yet no satisfactory pedo-transfer function for estimating an effective rooting depth that covers the largest possible spectrum of soil conditions, tree type and age class. In the light of this, we must stress the overview nature not only of Map 4.1 but also of Maps 4.2, 4.3 and 4.4, which show water-retention parameters.

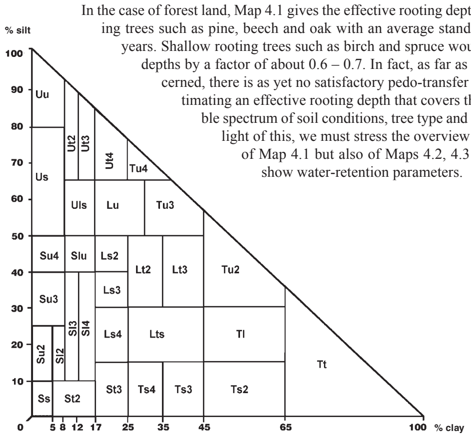

Fig. 2 **Soil texture classes**