Using different methods for calibrating field characterisation of soil hydrological qualities for vine and olive tree zoning.

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Abstract

In the territory of the Province of Siena (Central Italy) a soil survey for the evaluation of land suitability for viticulture and olive tree production was carried out at the reconnaissance scale. Also an experimental trial was set up aimed at calibrating field characterization of soil hydrological qualities. Twelve experimental plots with specialized vineyards and olive tree plantations, located in 6 different farms, were selected, the soils of which represented some of the main typologies utilized for the two crops. Besides routine field and laboratory analyses, bulk density, moisture content at different matric tensions, aggregate stability and coefficient of linear extensibility were measured. Soil moisture was measured with the gravimetric method, once a month for 13 months, at two depths. The functional EPIC model was utilized to produce a daily estimation of the soil water status. Three undisturbed soil samples were taken from each soil horizon for macroporosity measurement by image analysis on soil thin sections. A non-parametric statistical analysis was used to verify the relationships between classes of internal drainage and presence of redoximorphic features and all the laboratory and porosity parameters and the possibility of estimating these hydrological qualities from soil survey routine and non-routine data.

Results indicated that a year's monitoring of soil water content allowed the presence or absence of "aquic" condition in most profiles to be confirmed and the classes of internal drainage to be checked, although a longer period of monitoring would need to cope with climatic variations. Similar to monitoring, it was possible to estimate, through the use of the EPIC model the presence or absence of saturation water within the profile, but it gave different results in terms of times and seasons of the saturation period. The use of image analysis of porosity permitted the identification of the limited differences between the uppermost and deeper horizons and the lower porosity of the upper horizon of some soils, but the relationships with presence of redoximorphic features and classes of internal drainage were only evident for the most characterized profiles.

Key words: Soil Hydrological Qualities, Field Characterization, Vine and Olive Tree Zoning, Central Italy.

1. Introduction

It is well known that in Mediterranean countries the role that the physical and hydrological characteristics of the soil play is of utmost importance in determining vine and olive tree yield (Costantini, 1992; Costantini et al., 1996; Champagnol, 1997). For wine production, in particular, previous research work established that the productive and enological results of the vine correspond to a specific plant growth and ripening model, which is induced by agricultural practices, climate and soil conditions. The rationale is based upon the observation that environmental factors influence the hormonal equilibrium of each variety, which in turn regulates the expression of the genotype (Van Leeuwen and Seguin, 1997). Soil hydrological characteristics and soil water regime are among the main factors regulating water and oxygen supply for vine and olive trees, and consequently determining the stress conditions which affect hormonal secretion. They should be considered when carrying out any soil survey aimed at land zoning for vine and olive tree cultivation.

During the survey, soil hydrological qualities are taken into account in different ways. They are considered in soil classification, e.g. in Soil taxonomy (Soil Survey Staff, 1999), which states the presence of “aquic conditions” on the basis of a field description of the occurrence and evidence of redoximorphic features, i.e. mottles caused by the oxidation and reduction of iron and manganese compounds. They are also expressed as a soil quality, namely internal drainage, referring to the frequency and duration of periods when soil is wet (Soil Survey Division Staff, 1993). These indicators mainly come from routine field activity, and provide a first rough approximation. Several strategies can be applied and combined to improve these estimations. If technical reasons exclude the possibility of a continuous monitoring, as is generally the rule in the case of unrestricted and periodically cultivated fields, it is possible to relate field evaluations to measurements of moisture coming from benchmark soils (Costantini et al., 1996), use simulation models calibrated on specific environments (Ungaro and Calzolari, 2001), perform a number of laboratory tests, e.g. measurements of soil water content at different matric tensions, structural stability, etc. Recently, advances in the techniques of image analyses of soil thin sections also permit the quantification of the different aspects of soil porosity, which is one of the main characteristics influencing oxygen and water availability. The costs and the expertise needed to utilise this technique still prevent its routine application, but it can be adopted to improve understanding of the behaviour of benchmark soils and to correlate soil hydrological qualities not only in terms of classes, but also of pore quantity and typology.

The aim of this work was to set up a methodology which could be used to check routine field characterisation of soil hydrological qualities for vine and olive tree zoning. The trial compared the estimation of soil internal drainage classes and presence of redoximorphic features with i) water content monitoring of benchmark soils obtained through monthly measurements of soil humidity at two depths for about one year; ii) a simulation of the daily water content obtained with the EPIC functional model; iii) a micromorphological image analysis of porosity; iv) some statistical tests applied on routine and extra-routine analyses of physical, chemical and hydrological characteristics.

2. Materials and Methods

2.1. Field work and experimental setting

The trial was conducted in the Province of Siena (Central Italy), in the ambit of a vine and olive tree zoning, in conformation with the requirements laid out by local policy makers. A detailed explanation of the methodology used in the land evaluation project is reported in Costantini and Sulli (2000). On the basis of a reconnaissance soil survey of the entire province, 12 representative fields, situated in 6 farms, were chosen as benchmark soils. The experimental plots lay on slopes and do not have any permanent groundwater table. All the vineyards and olive tree plantations studied were deeply ploughed or ripped in the summer before plantation, as is usually done in the specialized farms, down to about 0.8 m. That entailed some homogenization of the profile and a fixed rooting depth. Agricultural husbandry of the crops includes surface cultivation aimed at weed control several times during the year.

The soils of the experimental vineyards and olive tree plantations were described, sampled, analyzed and classified according to Soil Taxonomy (Soil Survey Staff, 1999). A field assessment of soil internal drainage was obtained following the methodology laid out by the Soil Survey Division Staff (1993) and taken up by an Italian manual of soil description (Gardin et al., 1998). The meaning of the classes of internal drainage used was the following. Class 3, well drained: water is removed from the soil readily but not rapidly. Wet periods are not so long during the growing season that they significantly affect crop behavior or choice of the crop. These soils are mainly free of redoximorphic features (less than 4-5% by volume) within the rooting depth. Class 4, moderately well drained: water is removed from the soil somewhat slowly during some periods of the year. The soils are wet for only short times during the growing season, but long enough that most mesophytic crops and agricultural husbandry are affected. They commonly have a moderately low or lower saturated hydraulic conductivity in a layer within the upper 1 m and show common redoximorphic features (more than 4-5%), at least in the lower part of the rooting depth. Class 5, somewhat poorly drained: water is removed slowly so that the soil is wet at a shallow depth for significant periods during the growing season. Mesophytic crops and agricultural husbandry are deeply affected. The soils commonly have a low saturated hydraulic conductivity or additional water from seepage. They show common redoximorphic features within the rooting depth.

Measurements of the soil moisture were obtained by the gravimetric method, on samples taken with an auger about once a month for 13 months, at two depths (0.1-0.3 m and 0.4-0.7 m).

2.2. Laboratory analyses

Besides routine laboratory analyses (particle size, pH, carbonates, electrical conductivity, organic matter, cation exchange capacity) carried out in accordance with Italian official standards (Ministero delle Politiche Agricole e Forestali, 2000), a set of physical and hydrological characteristics, i.e., bulk density (core method), moisture content at different matric tensions (sand box and Richards pressure plate extractor, Kassel and Nielsen, 1986) and coefficient of linear extensibility (COLE) were measured (Grossman et al., 1968). To evaluate soil aggregate stability, the mean weight diameter (MWD) of water stable aggregates was determined by the procedure described by Kemper and Chepil (1965). Air dried aggregates in the range of 4-2 mm were put directly on the top of a nest of sieves of 2, 1, 0.5, 0.25 mm immersed in water. The nest of sieves was then oscillated vertically in water by a machine with a stroke of 40 mm, at a rate of 30 complete oscillations per minute, per 10 minutes. The mass of oven-dried particles (105°C for 24 hours) in each sieve that resisted breakdown was determined. The respective dry masses were used to compute the MWD.

Periodic measurements of the gravimetric water content were converted into volumetric with bulk density, then the values were transformed into soil matric potential and the annual geometric mean was calculated. The transformation of volumetric water content to potential was obtained using the multiple linear regression approach proposed by Rawls (1992). This method considers total sand, silt and clay, organic matter content, bulk density, wilting point, and field capacity.

2.3. Porosity analysis

In order to evaluate the pore system of the soils of the 12 representative fields, undisturbed soil samples from different horizons were taken in triplicate. Samples were dried by acetone replacement (Miedema et al., 1974), impregnated with a polyester resin and made into 6x7 cm vertically oriented thin sections (Murphy, 1986).

Thin sections were prepared and two images were captured with a video camera from each section. These images covered 4.5x5.5 cm^2 of the thin section, avoiding the edges where disruption could have occurred. The images were analyzed by means of the image analysis techniques using the Image-Pro Plus software produced by Media Cybernetics (Silver Spring, USA). The instrument was set up to measure pores larger than 50 µm. Pore shape factor was expressed as $perimeter^2/(4\pi * area)$. Using the shape factor, pores were divided into regular pores (shape factor 1-2), irregular pores (shape factor 2-5) and elongated pores (shape factor >5). These classes correspond approximately to those used by Bouma et al. (1977). Pores of each shape group were further subdivided into size classes according to either the equivalent pore diameter for regular and irregular pores, or to the width for elongated pores (Pagliai et al., 1984). Thin sections were also checked for microstructures using a Zeiss "R POL" microscope at 25x magnification. The statistical analysis of the results was carried out by one way analysis of variance (ANOVA) and means separation by the least square differences (LSD) test.

2.4. The simulation with the EPIC model

The EPIC (Erosion-Productivity Impact Calculator) model (Sharpley and Williams, 1990) was used to simulate daily soil moisture. Daily climatic input of the EPIC's weather generator were minimum and maximum air temperature, relative humidity, rainfall and radiation. The Priestley-Taylor (Priestley-Taylor, 1972) method was used to estimate potential evapotranspiration. The reference crops in input were vine and olive tree, cultivated without irrigation, and with the actual husbandry of the experimental fields. Other crop parameters were those provided by EPIC as default values. Soil input data came from profile description and analysis, and considered horizon depth, texture, field capacity and wilting point estimated by the Richards method, bulk density, organic carbon, pH, total carbonate, exchangeable bases and cation exchange capacity. The EPIC model was initialized at field capacity and a simulation was run with the actual climatic data of the year under study. Then, using the long term climatic data and the weather generator, the EPIC model was run for a 50 year period.

2.5. The statistical analysis

The results of the simulation obtained with the EPIC model were compared with the measured water contents on the same day. Three statistical indices of accuracy were utilized: the average error (AE), the root mean square error (RMSE) and index of agreement (IoA). The AE compares the mean of predicted and observed values for the entire period studied. The RMSE measures the difference between predicted and observed values in quadratic terms, therefore it is sensitive to the extreme values. The IoA is a standardized RMSE. It can vary from 0, total disagreement, to 1, total agreement, between predicted and observed values.

The statistical analysis used the Kruskal-Wallis non-parametric test to find significant relationships between the two hydrological qualities, classes of internal drainage and presence of redoximorphic features, and all the laboratory and porosity parameters. The choice of a non-parametric test was justified by the non-homogeneity of the variance of many parameters.

3. Results and discussion

3.1. Climate and soils of the study sites.

Only two out of the six experimental farms were equipped with meteorological stations. For the others, the data came from the closest available station. The distance in these cases ranged from 2 to 10 km. Long-term mean annual air temperature of the vineyards and olive tree plantations ranges between 13.5 and 14.8°C, with maximum in July and minimum in January, and little yearly and monthly standard variation of the long-term means. The long-term mean annual rainfall is between

749-834 mm. Summer months are usually dry and behavior is predictable, autumn and spring months are the most rainy and are rather variable, especially September. The studied year had a normal rainfall, that is a total amount of rain comprised between standard deviation of the long term means (30-49 years), in all farms but at Palazzone. Here rainfall was less than usual, especially in springtime and autumn, so that rains were more distributed during the year. Among experimental fields with normal precipitation, at Campriano and Trecciano springtime was less rainy than the long-term average, while at Strove springtime and autumn were even more rainy than normal.

The soils studied have rather different parent materials, pedogenesis (Entisols, Inceptisols and Alfisols) and topography (Tab. 1), but their internal drainage estimation only ranges from 3 (well drained) to 4 (moderately well drained) and 5 (somewhat poorly drained). The presence of redoximorphic features determines soil classification with the "aquic" qualifier, depending on their depth of occurrence, quantity and degree of evidence.

3.2 Soil moisture monitoring during the studied year

Monitoring water content every month allowed us to appreciate during which times and seasons soils were more or less saturated during the study period. If we take into account the differences in climate between the studied year and the normal year, we can utilize this observation to verify classes of internal drainage as well as the classification of the soils' within "aquic" subgroups, which was based upon field appreciation of presence of redoximorphic features. The monitoring confirmed the presence of "aquic" conditions in six out of nine profiles classified within "aquic" subgroups. These soils showed in one or more measurements the presence of saturation water, i.e. a water content (w/w) higher than that found with the Richards method at -0.33 bar, either at 10-30 and/or at 40-70 cm. Only profiles 6, 7 and 8, which were classified "aquic", never showed the presence of saturation water during the trial. This inconsistency might be due to the fact that these experimental fields received less rain in the studied period than during normal years. On the other hand, the soils classified as not having the "aquic" qualifier never had saturation water. The only exception was profile 40, which showed temporary saturation in the upper part of the soil, even if redoximorphic features were not evident. In the studied year, however, this site had a particular concentration of rainy events during the moister seasons, but we can not exclude a mechanically induced compaction of the horizon (bulk density 1.72 g.cm^{3}).

As regards the relationships between monitoring of soil water content and classes of internal drainage, the two profiles belonging to class 3 (well drained) actually showed the presence of saturation water in the first (profile 40) or in both layers (profile 5). In the first case the inconsistency could be explained by the same reasons as above, while in the second case we must recognize a probable misjudgment, possibly due to the underestimation of the effects on internal drainage of the deep Bt horizon, loamy in texture and well structured, but with a high amount of redoximorphic features (Tab. 1). The two moderately well drained soils (profiles 1 and 42) were classified as never being saturated in the considered horizons. Although we do not know if water saturated horizons deeper than 70 cm, the attribution of these soils to class 4 of internal drainage could be questionable. In the case of profile 42, in particular, the fine texture could have biased the estimation of saturated hydraulic conductivity. In 4 out of the 8 somewhat poorly drained soils (profiles 2, 3, 4, and 94) saturation water was present at both depths in some measurements, and within the uppermost layer in profile 41, but never in the remaining profiles 6, 7 and 8. These last soils however, as mentioned above, received less rain in the studied period than during normal years. Figure 1 shows the exemplifying case of profile 94, belonging to field estimated class 5 of internal drainage.

3.3 Soil moisture estimation with the EPIC model

The EPIC model was run to simulate soil water content of all the experimental soils during both the study year and on a long term basis. The comparison between long term and year simulations was added to appreciate how much the pedoclimate during the studied year was similar to that of the normal year.

The indices of agreement (IoA) between observed and estimated values of water content at the two considered depths and for the 13 monitored months were always more than 0.60. The average errors (AE) did not indicate a clear tendency to systematically overestimate or underestimate the moisture. The root of the mean squared differences (RMSE) ranged between 0.028 and 0.066, values which can be considered rather low and comparable to those found by other authors in similar experiences (Ungaro and Calzolari, 2001). No interaction was observed between classes of internal drainage and statistical reliability of the EPIC simulation, which means that the EPIC simulation did not result as being biased by the better or poorer drainage conditions.

If we take into account the values of volumetric water content at field capacity, obtained through the Richards method and field bulk density, we can compare the length of wet periods highlighted by EPIC, with the times when the soils were found wet and with their classes of internal drainage. In the case of exemplifying soil profile 94, belonging to the somewhat poorly drained class, saturation in the uppermost layer occurred only during wintertime but, in the deeper layer, from the middle of autumn to the middle of spring. On the other hand, EPIC predicted a much longer saturation in both layers (Fig.2).

As a general rule, the evaluation provided by the two methods, EPIC and monitoring, was similar in terms of presence or absence of saturation water, but not for times and seasons of the saturation period. In this sense, a better correspondence was obtained during the more characterized periods of the year, winter and summer, while it was rather different during the medium seasons.

3.4 Statistical analysis of the relationships between soil hydrological qualities and laboratory and porosity parameters

The Kruskal-Wallis non-parametric test, applied to the experimental soils, found significant relationships between classes of internal drainage and: field capacity and wilting point, pH, silt, clay and total sand ($P \leq 0.001$); COLE, fine sand, regular pores in the 50-100 μm and 100-200 μm size classes ($P \leq 0.01$); very fine sand, regular pores in the 200-300 μm size class and total pores of size

50-100 µm ($P \leq 0.05$). The presence of redoximorphic features instead resulted significantly correlated with: organic carbon and pH ($P \leq 0.001$); available water capacity, coarse and medium sand, and structural stability ($P \leq 0.01$); wilting point, COLE and very coarse sand ($P \leq 0.05$).

3.5 Soil hydrological quality through image analysis of porosity on thin sections.

Porosity values, obtained by image analysis of thin sections, were analysed by ANOVA, comparing the uppermost (1) with the deeper (2) horizons. The aim of this comparison was to verify the response of the investigated soils to the perturbation caused by deep ploughing. In most cases, soil porosity decreased going down to the deeper horizons (Tab. 2). Nevertheless, significant differences can be noted only for regular and irregular pores. Elongated pores and total porosity, even if showing the same decreasing trend, did not show statistical differences. In particular, in soil profiles 3 and 41, in which olive trees were present, the deeper horizons are more porous than the upper ones, probably due to persisting effects of deep ploughing (Fig. 3).

Soil porosity values were also compared by profiles, with the aim of highlighting a possible relationship with internal drainage class. Statistical analysis did not show significant differences either for total porosity or for regular, irregular and elongated porosity values. However, considering pore size class distribution, statistical differences were pointed out for elongated pores of size class 100-300 µm. This outcome is important because, according to Greenland (1977), pores of this size class belong to “transmission pores”, hence directly relating to soil hydrological properties. Elongated porosity showed the same trend as total porosity (Tab. 3).

With regard to the relationship between porosity and internal drainage class, the profiles with the highest porosity values were both coarse textured, but profile 1 belonged to drainage class 4, while profile 4 was judged as class 5 (Tab. 1). On the other hand, the four profiles showing the lowest porosity values, all fine and fine silty textured, generally had the worst internal drainage class, with the exception of profile 42, which was ascribed drainage class 4.

With respect to the relationship between porosity and redoximorphic features, the comparison was made by horizon (Fig. 3). In the uppermost horizons redoximorphic features were detected only in profiles 6, 7 and 8 (Tab. 1); although profile 7 showed the lowest total porosity and the highest percentage of redoximorphic features (15%), it was not possible to clearly identify a threshold in porosity between horizon with and without redoximorphic features, the same holding true for the lowermost horizons.

4. Conclusions

The four proposed methods for checking the field assessment of soil internal drainage and presence of redoximorphic features showed all, as expected strong and weak points.

The year's monitoring of soil water content allowed confirmation of the presence or absence of "aquic" conditions in most profiles, but some of them remained in doubt. A longer period of monitoring, at least two or three years of measurements, may be needed to cope with climatic variations. Similarly, for an exhaustive checking of the classes of internal drainage, a longer period of measurement is recommended. Even with only one year observation period, however, it was possible to individuate a probable case of misjudgment and its possible causes.

The use of the EPIC model gave rather good results in terms of statistical reliability of the water content simulation in the experimental vineyards and olive tree plantations. Similarly to monitoring, EPIC estimates the presence or absence of saturation water within the profile, but it gives different results in terms of times and seasons of the saturation period. Yet, one of EPIC's strong points is the possibility to simulate water content over a long term period and to relate it to the year of observations. The non parametric statistical test indicated that the parameters correlated with classes of internal drainage were field capacity and wilting point, pH, clay, silt, very fine, fine and total sand, COLE, regular pores in the 50-100 μm, 100-200 μm and 200-300 μm size classes, and total pores of size class 50-100 μm. The presence of redoximorphic features instead resulted significantly correlated with organic carbon, pH, available water capacity, very coarse, coarse and medium sand, structural stability, wilting point and COLE. The image analysis of porosity permitted the explanation of the specific physical and hydrological condition of each soil horizon, rather than the checking and calibration of field assessment of hydrological qualities. However, in spite of the reduced number of samples and replications, the use of image analysis of porosity permitted highlighting that differences between the uppermost and deeper horizons are limited, probably due to the permanence of the influence of the deep ploughing made before tree plantation. On the other hand, the relationships with presence of redoximorphic features and classes of internal drainage were evident only for the most characterized profiles.

As a whole, the results obtained show that the combination of the different methodologies tested may be applied to achieve a better characterisation of soil hydrological qualities, and improve land evaluation for vine and olive tree zoning.

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Table 1: Experimental settings.

Farm and crop	Soil Profile (n°)	Site description	Soil classification (Soil Taxonomy, 1998)	Depth and quantity of redoximorphic features (cm)	Class of internal drainage*
Modanella vine	1	Alluvial terrace, 2% slope; elevation 330 m; aspect 180°(S); parent material is mainly sandstone	Alfic Xerarent, loamy skeletal	10-50; 25% 50-90; 20% 90-150+; 7%	4
Modanella vine	2	Middle part of a slope, 6%; elevation 325 m; aspect 180°(S); parent material is clayey marl	Aquic Haploxerept, fine	20-60; 4% 60-125; 7%	5
Modanella olive tree	3	Alluvial terrace, 8% slope; elevation 370 m; aspect 180°(S); parent material is mainly sandstone	Aquic Haploxeralf, fine loamy	15-50; 75% 50-90; 35% 90-110; 15%	5
Colle Trequanda vine	4	Convex slope, 4%; elevation 425 m; aspect 270°(O); parent material are coarse, medium and fine sands.	Aquic Xeropsamment, coarse loamy	0-15; 4% 15-60; 5% 60-100+; 6%	5
Colle Trequanda olive tree	5	Upper part of a slope, 18%; elevation 425 m; aspect 270°(O); parent material are coarse, medium and fine sands.	Aquic Haploxeralf, fine loamy	0-10; 1% 10-32; 2% 32-70; 1% 70-95; 21% 95-130+; 5%	3
Campriano vine	6	Convex slope, 2%; elevation 280 m; aspect 158°(SSE); parent material is clayey marl.	Aquic Haploxerept, fine	0-30; 5% 30-55; 2% 55-100+; 10%	5
Campriano vine	7	Medium part of a slope, 25%; elevation 275 m; aspect 135°(SE); parent material is silty marl.	Aquic Haploxerept, fine	0-30; 15% 30-60; 23%	5
Palazzone vine	8	Convex slope, 2%; elevation 328 m; aspect 45°(NE); parent material is silty marl.	Aquic Haploxerept, fine silty	0-20; 5% 20-75; 8% 75-120+; 18%	5
Strove olive tree	40	Lower part of slope, 15%; aspect 338°(NNO); parent material are colluvial deposits of cobbles and very fine sand and silt.	Typic Haploxerept, loamy skeletal	absent	3
Strove olive tree	41	Alluvial terrace, 15% slope; aspect 339°(NNO); parent material are clay and quartzite.	Aquic Haploxeralf, fine	40-90; 25% 90-145; 23% 145-200+; 12%	5
Trecciano vine	42	Terraced bottom part of a doline, 2% slope; elevation 400 m; parent material is residual clay	Typic Haploxerept, fine	100-150+; 8%	4
Palazzone vine	94	Convex slope, 15%; elevation 400 m; aspect 45°(NE); parent material is clayey marl	Aquic Haploxerept, fine	0-20; 2% 20-60; 3% 60-140+; 17%	5

*3: well drained, 4: moderately well drained, 5: somewhat poorly drained

Table 2: Macroporosity expressed as a percentage of area occupied by pores larger than 50 μm per thin section in the two different compared horizons of all soils. In each column, values of porosity differ significantly when followed by different letters at $P \leq 0.05$ using LSD test.

	Regular pores	Irregular pores	Elongated pores	Total porosity
All surface horizons	1.77 a	1.97 a	2.47 a	6.21 a
All sub-surface horizons	1.22 b	1.29 b	1.81 a	4.32 a

Table 3: Mean macroporosity values for each profile, expressed as a percentage of area occupied by pores larger than 50 μm. In each column, porosity values measured by image analysis on soil thin sections differ significantly when followed by different letters at $P \leq 0.05$, using LSD test.

Profile n.	Regular Pores	Irregular Pores	Elongated Pores	Elongated Pores of size class 100-300 μm	Total Porosity
1	1.89 a	2.10 a	4.38 a	1.13 a	8.37 a
2	1.04 a	1.28 a	1.92 a	0.73 ab	4.24 a
3	1.52 a	1.71 a	1.60 a	0.62 ab	4.83 a
4	1.49 a	1.39 a	4.34 a	0.80 a	7.22 a
5	2.12 a	2.23 a	2.00 a	0.70 ab	6.35 a
6	1.52 a	2.24 a	1.85 a	0.62 ab	5.61 a
7	0.87 a	0.50 a	0.15 a	0.01 b	1.51 a
8	0.85 a	0.99 a	0.38 a	0.05 b	2.22 a
41	2.00 a	2.13 a	1.97 a	0.74 ab	6.10 a
42	1.21 a	1.42 a	1.05 a	0.13 b	3.68 a
94	1.30 a	1.36 a	0.39 a	0.12 b	3.05 a

Table 1: Experimental settings.

Table 2: Macroporosity expressed as a percentage of area occupied by pores larger than 50 μm per thin section in the two different compared horizons of all soils. In each column, values of porosity differ significantly when followed by different letters at $P \leq 0.05$ using LSD test.

Table 3: Mean macroporosity values for each profile, expressed as a percentage of area occupied by pores larger than 50 μm. In each column, porosity values measured by image analysis on soil thin sections differ significantly when followed by different letters at $P \leq 0.05$, using LSD test.

Figure 1

Water fractions at two depths in a soil belonging to class 5 of internal drainage (somewhat poorly drained).

Figure 2

Volumetric soil water content, measured vs simulated with the EPIC model, using climatic data of 1999 and of long term period. The volumetric field capacity is 0.24 at 10-30 cm and 0.22 at 40-70 cm (Richards method and field bulk density). AE, RMSE and IoA of the estimation with EPIC at 10-30 cm are -0.010, 0.028 and 0.89; at 40-70 cm are 0.037, 0.051, 0.64.

Figure 3

Macroporosity expressed as percentage of area occupied by pores larger than 50 μm in the two considered horizons. Total porosity values differ significantly when marked with different letters at $P \leq 0.05$ using LSD test.

Figure 1

Water fractions at two depths in a soil belonging to class 5 of internal drainage (somewhat poorly drained).

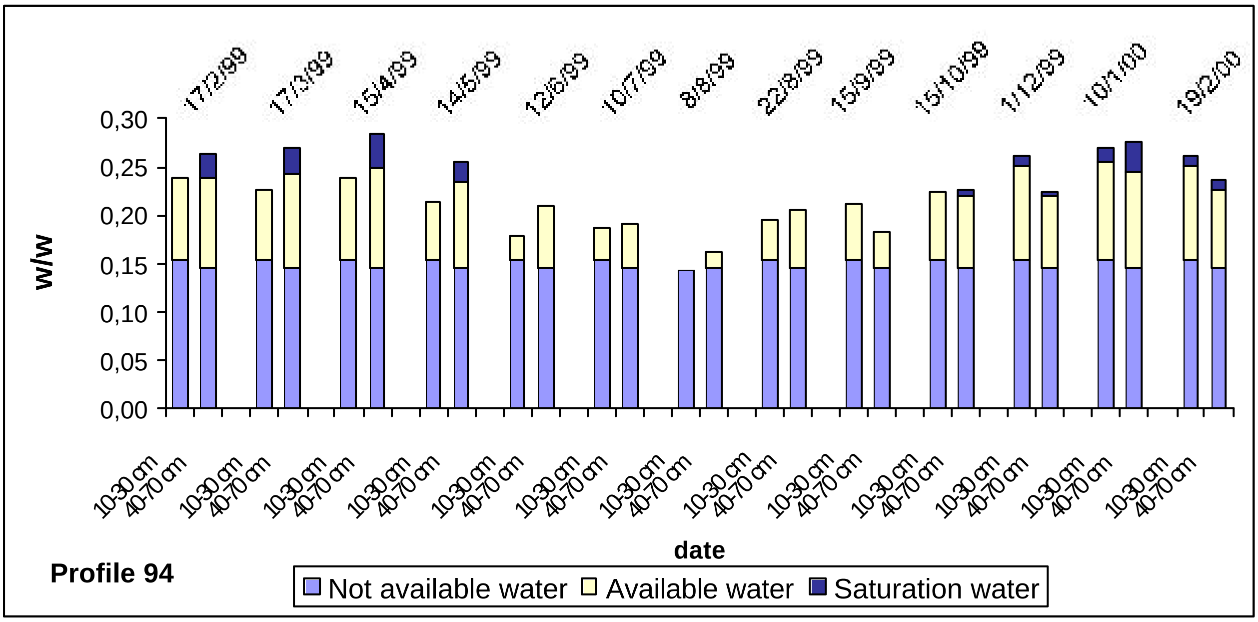
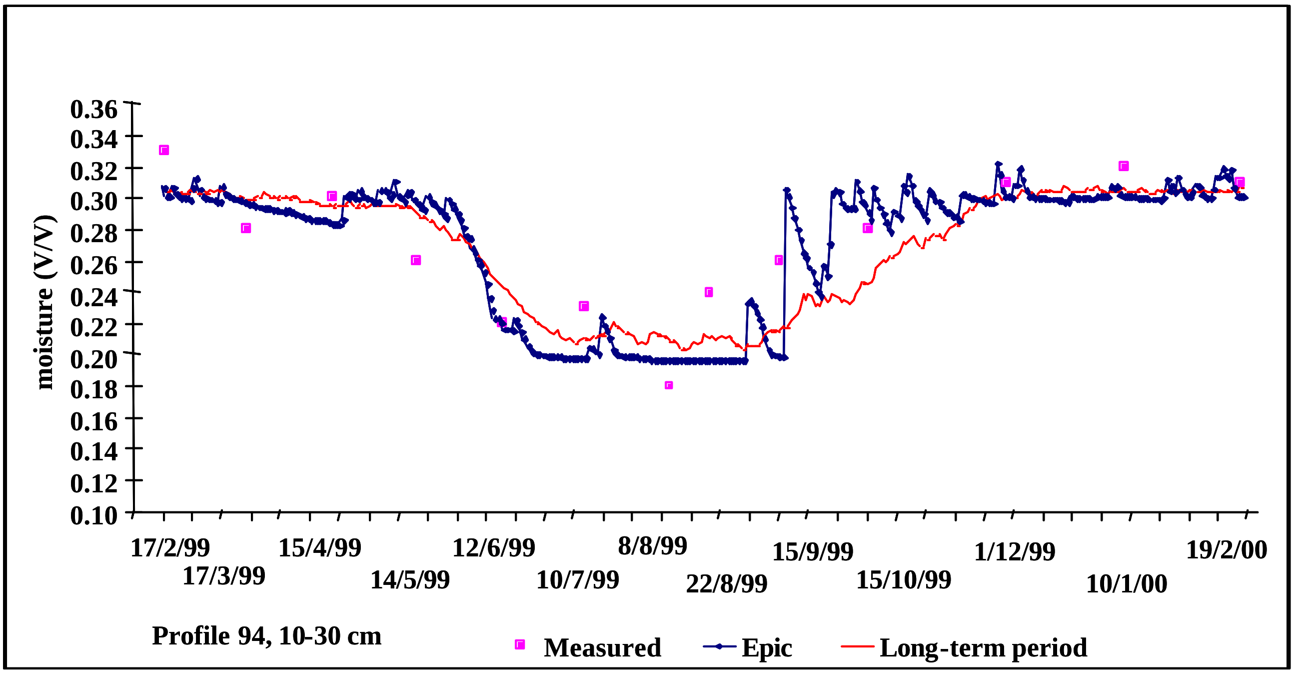


Figure 2

Volumetric soil water content, measured vs simulated with the EPIC model, using climatic data of 1999 and of long term period. The volumetric field capacity is 0.24 at 10-30 cm and 0.22 at 40-70 cm (Richards method and field bulk density). AE, RMSE and IoA of the estimation with EPIC at 10-30 cm are -0.010, 0.028 and 0.89; at 40-70 cm are 0.037, 0.051, 0.64.



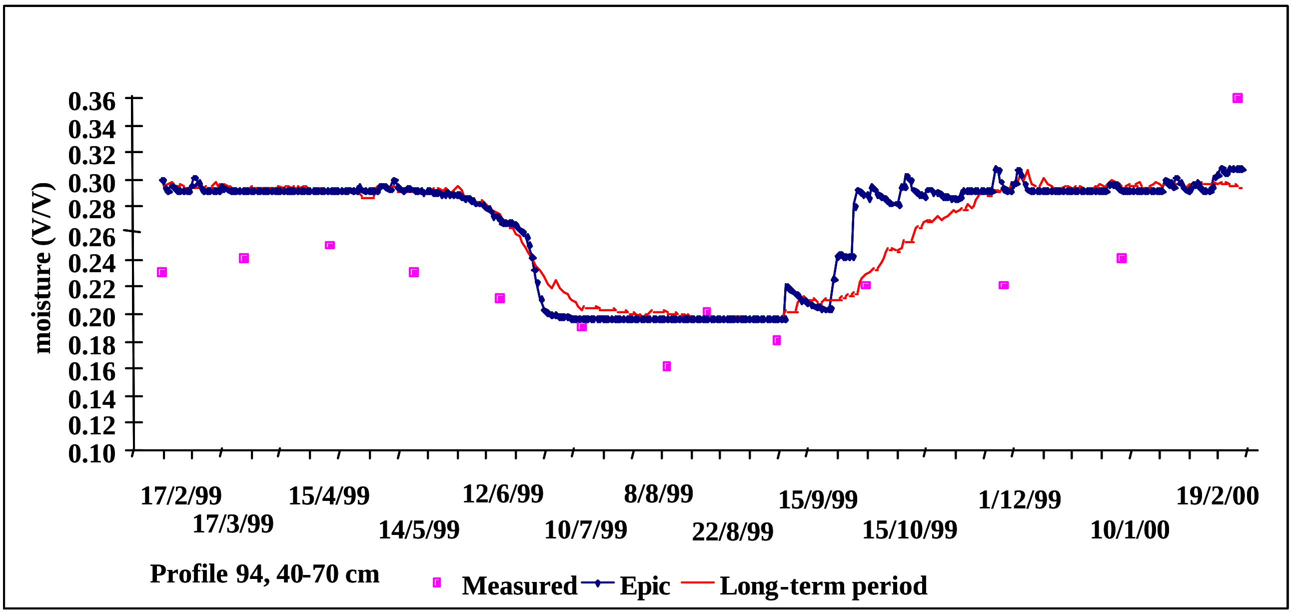


Figure 3

Macroporosity expressed as percentage of area occupied by pores larger than 50 μm in the two considered horizons. Total porosity values differ significantly when marked with different letters at $P \leq 0.05$ using LSD test.