WATER SUPPLY FROM THE GROUNDWATER TABLE AND THE GROWTH OF POPLAR: A CASE STUDY

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Forest growth and the growth of poplar in particular is related to water availability. Water supply through capillary rise from the groundwater table up to the rooted soil layers is a determining factor of the water balance.

The water halance model SWATRER was used to explain the extreme growth differences in a 2-ha large poplar plantation. Water supply through capillary rise was estimated for 37 sites and related to different growth parameters.

This study revealed that the simulation model SWATRER is a useful tool in growth site research. In particular, the site indexes S_{00} and S_{10} showed a good correlation with water supply. Girth growth showed the highest correlation.

In conclusion it was suggested that a poplar-specific girth growth model should be developed and the sink term parameters, potential evapotranspiration and interception should be defined more precisely.

The results show the necessityfor further research into clone-specific water requirements and the development of a simplified water balance model, adapted to growth-site research.

INTRODUCTION

Up to 80% of the annual variation in the xylem increment of forest trees in humid regions bas been attributed to water deficits (Koslowski, 1982). As far as poplars are concerned, a positive and linear relationship was found between transpiration and basal area increment and dry matter production in lysimeter trials (Hammes, 1983). Available water capacity of the soil was related indirectly to yield level for *Robusta* (van den Burg; 1987) and for quaking aspen (Succof, 1982).

A more complex approximation was used by Le Goff and Levy (1984), introducing potential evapotranspiration, soil depth and topography as indexes of water availability in relating site to productivity of European ash.

The water balance model LAMOS was used by Wösten et al. (1984) to relate moisture deficits to annual basal area increment of Scotch pine over a period of 13 years.

An important term of the water balance is the water supply through capillary rise from the groundwater up to the rooted soil layers. This water supply is determined by the depth of the groundwater table and the heterogeneity of texture and structure of the successively deposited soil layers (Giesel et al., 1972), especially on alluvial soils, where poplars are usually cultivated. Simulation of this water supply by means of a model for water balance might be a tool to explain growth differences and to relate site properties to yield.

The influence of the water supply through capillary rise on the growth of a 15-year-old monoclonal poplar plantation was studied. By relating water supply to different growth parameters, the response of each growth parameter was evaluated in order to use the most appropriate growth parameter as input value for growth-site relationships.

MATERIALS AND METHODS

A 2-ha large poplar plantation of the Belgian clone Ghoy at Berlare (East Flanders) shows extreme variation of growth. This plantation was establîshed

TABLE 1

Mean value, range and standard deviation of the horizon thîckness, depth of the lower bóundary of the horizons and depth of the reduction horizon of the 37 auger samples of the plantation at Berlare

	Horizon			
	IAp	ICg	neg	G
Thickness (cm)				
Mean	57	17	98	
Minimum	10	0	25	
Maximum	70	70	170	
Standard deviation	1L2	15.3	43.3	
Depth (cm)				
Mean	57	72 .	170	170
Minimum	10	50	95	95
Maximum	70	100	230	230
Standard deviation	11.2	10.6	41.0	41.0

in 1974, using 2-year-old plants and a spacing of 8X 8 m. The plantation is situated in an old meander of the Scheldt. The soil can be classified as an haplaquent. A soil survey by 37 auger samples in a fixed screen, revealed the following horizon sequence: IAP, sandy clay/sandy clay loam; ICg, sandy clay/ sandy clay loam; IICg, loamy sand/sand; G, loamy sand/sand. Mainly the thickness of those horizons varies from one auger sample to another (Table 1). Rooting is limited to the upper soil layers IAP and ICg.

In addition, profiles on three representative sites were studied. The following physical parameters of each horizon were determined: particle size distribution (0-2, 2-50 and >50 μm), dry bulk density, soil water content at suction levels equivalent to pF 0.0, 1.0, 2.0, 2.54, 3.01 and 4.19, organic matter content and saturated hydraulic conductivity. During 1986, the groundwater level and the moisture content every 25 cm down to the groundwater table were also measured every 2 weeks near those three profiles.

In order to evaluate gro'Wth, the four trees around each auger sampl were measured and the following growth parameters were defined:

S'X>: theoretica! asymptotic value of height in metres according to the Chapman-Richards growth model

$H = S_{oo}(1 - eat) P$ H = *mean* height, t = age, a and P = parameters

8_{10}: theoretical height at age 10 years according to the following growth model

$H = ao + a_1 t + a_2 S + a_3 tS + a4t^2$ and $8 = 810 O - b1)/bo$

Both S values are frequently used as input for yield tables (Goossens et al., 1988). H_{12}, H_{15}, C_{12}, C_{15}, G_{12}, G_{15}, V_{12} and V_{15} respectively are height, circumference, basal area arid volume at age 12 and 15 years.

$iH2\_{5}$, iH_{6-10}, iH11_1..: periodic height increment.

Their average, range and sandard deviation are given in Table 2.

To relate the variation of the growth parameters with the terms of the water balance, capillary rise from the groundwater table during the growing season of 1986 was simulated by the model SWATRER (Dierckx et al, 1986). This model was run for each auger sample. The model is a revised version of the SWATRE model (Belmans et al., 1983). It is a one-dimensional transient finite difference model for the unsaturated zone, using an implicit numerical scheme with explicit linearization solving Richards flow equation. Profile root zones composed of up to five different layers and seven different bottom boundary conditions can be handled by the model.

Potential evaporation, precipitation, interception and sink term are common input values for the 37 auger samples. Daily values of potential evapotranspiration of deciduous forest for 1986 (Fig. 1) were available from the meteorological station at Melle, which is -- 12 km distance from the plantation. These values are based upon estimation of the evaporation of a fictional free

TABLE 2

Mean value, range and standard deviation of the growth parameters at the plantation at Berlare

Growth parameter	Mean	Minimum	Maximum	Standard deviation
8.-;e; (m)	3:3.9	2ï .3	39.8	;t18
8_{10} (m)	11.4	9.2	ia.6	1.13
Hi2 (m)	14.6	11.5	17.3	1.48
H15 (m)	18.9	15.8	22.6	1.67
$C\backslash_2$ (cm)	69.9	47.1	89.6	12.99
$C\backslash_5$ (cm)	96.4	74.3	120.5	11.a2
G_{12} (cm^2)	393.0	178.4	641.7	120.51
$G1_5$ (cm^2)	765.8	440.5	1156.8	175.22
V12 (dm^3)	240.5	88.8	436.9	90.00
V_{15} (dm^3)	465.6	282.5	992.8	169.82
iH_{2-5} (m)	1.5	0.9	2.0	0.29
iHs-10 (m)	fi.8	4.2	Î.6	0.95
iH11-1.r; (m)	8.0	7.0	9.6	0.66

water surface, according to Penman (1948) and Rijtema (1965), and transferred to deciduous forest (Bultot and Dupriez, 1974). Daily precipitation values could be used from the nearer station at Dendermonde (at .-- 8 km) (Fig. 2). A maximum value of 2 mm day^{-1} of interception was accepted. The sink term, describing the root water extraction, was described according to Hoogland et al. (1981).

To run the model, soil physical characteristics appropriate to each auger sample were necessary. The soil physical parameters were estimated for each horizon of the three profiles. The moisture retention chatacteristic was described by a modified form of the Van Genuchten equation (Van Genuchten and Nielsen, 1985), while the unsaturated hydraulic conductivity was described by the Gardner (1958) equation. The parameters in these equations were estimated from particle size information, bulk density, organic matter content and saturated hydraulic conductîvity (Vereecken et al., 1988a,b). The results were compared to the available measured soil physical values of the profiles. Subsequently, according to the individual elevation and aspect of the horizon sequence of each auger sample, the soil physical parameters of the corresponding profile were taken as input.

Daily values of the groundwater level during the growing season of 1986 were needed as bottom boundary condition. They were estimated linearly from the fortnîghtly records of the groundwater level near each profile and adapted to each augering according to their elevation. Rooting depth was equated with the total thickness of the IAP and ICg horizons.

The model outputs are the actual evapotranspiration, the capillary rise and amount of drainage during the growing season, and the variation of the soil

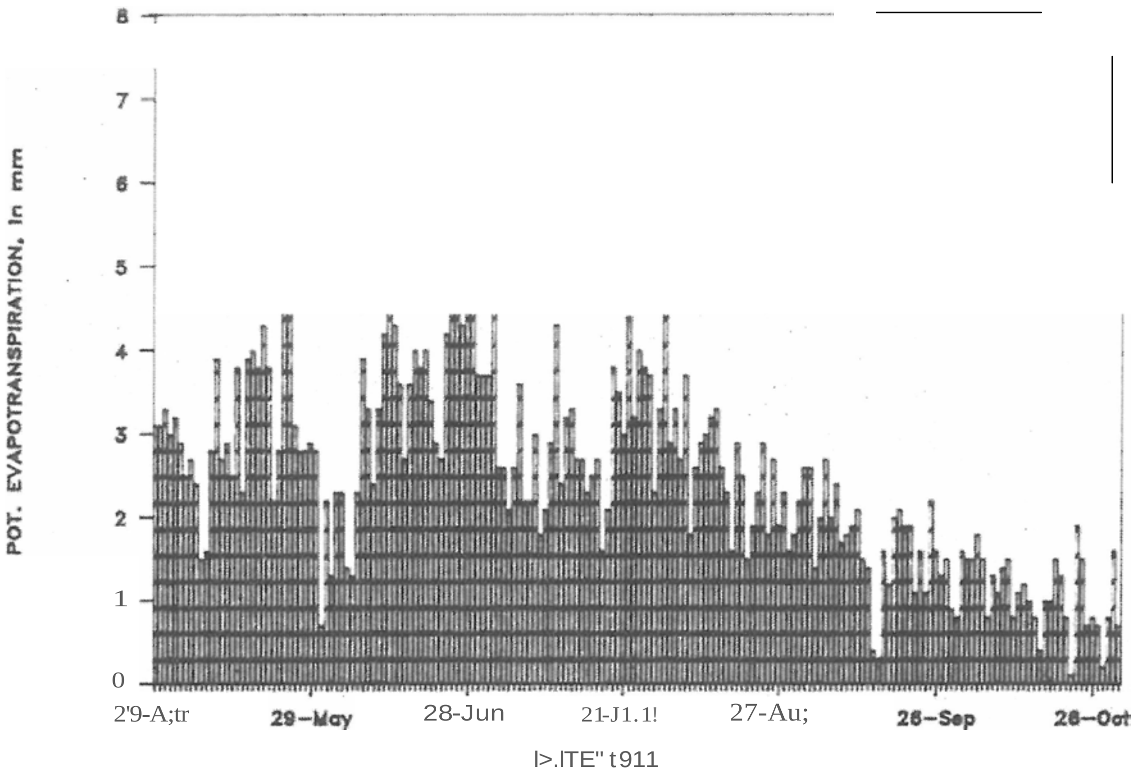

Fig. 1. Daily potential evapotranspiration of deciduous forest for 1986 (meteorological station at Melle).

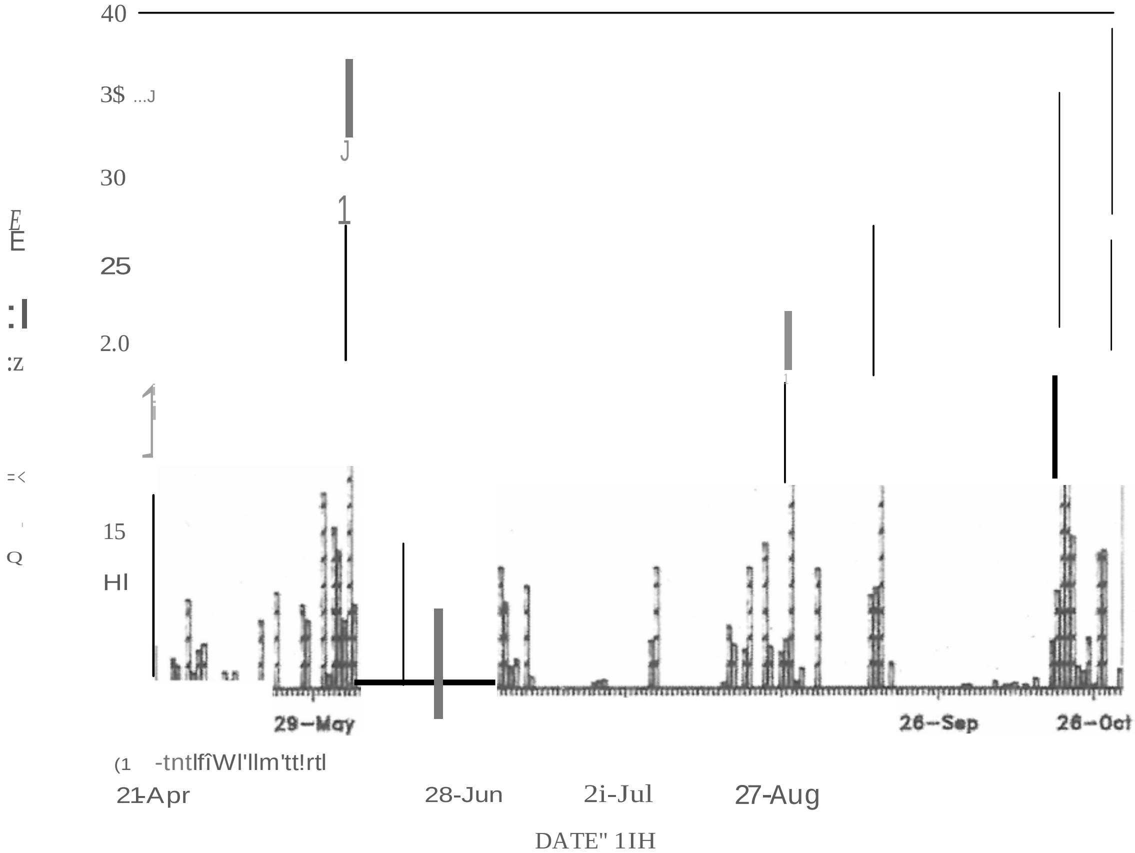

Fig. 2. Daily rainfall at the meteorological station at Dendermonde for 1986.

water content for each horizon. Soil moisture content at different depths and dates, and the water supply at the bottom of the rooted horizon through capillary rise, were retained from those outputs.

Finally, regression analysis was used to investigate the relationship between the growth parameters and the water suppl.Y at the bottom of the rooted zone, integrated over the growing season of 1986.

RESULTS AND DISCUSSION

The performance of the water balance model was visually compared to field data using the fortnightly measured soil moisture profiles, obtained at the three representative sites. This comparison inclicated that a close similarity was achieved between calculated and measured moisture content, particularly for the lower horizons, except for the moisture content of the IAP horizons, which was underestimated. This is illustrated by Figs. 3 and 4, showing a comparison between the estimated and the förtnightly measured soil moisture contents, respectively, at a depth of 25 cm (IAP) and 75 cm (ICg) for profile No. 18.

The underestimation of the water content of the upper soil layer might be attributed to an insufficient knowledge of poplar specific evapotranspiration

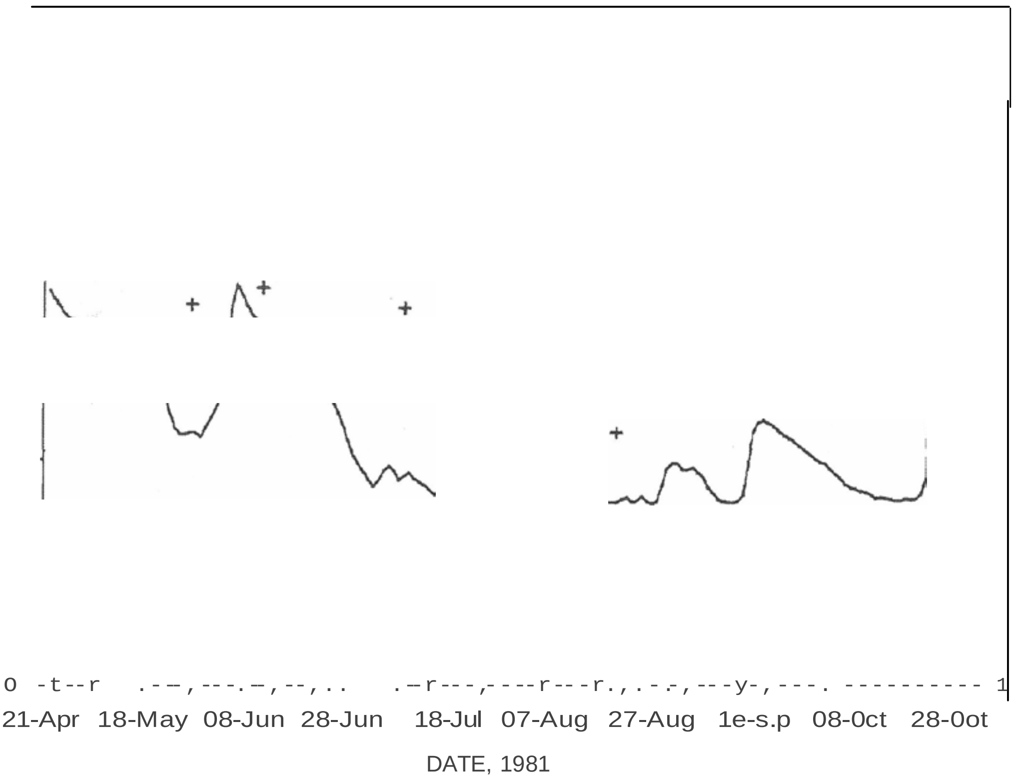

Fig. 3. Comparison hetween the estimated (-) and the fortnightly measured moisture contents (+) at a depth of 25 cm (IAP) for profile No. 18.

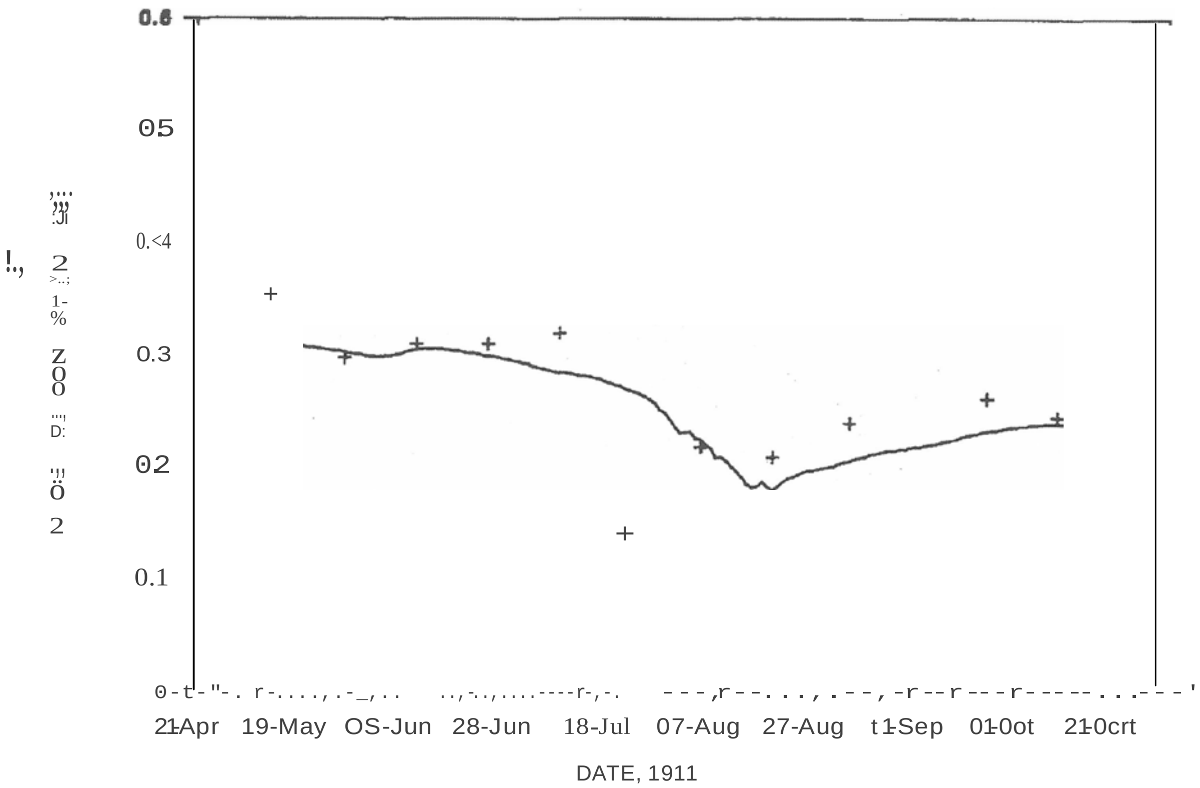

Fig. 4. Comparison between the estimated (-) and the fortnightly measured moisture contents (+) at a depth of 75 cm (IC,) for profile No. 18.

and interception rates, particularly in relation to crown development at fixed spacings. Another possibility might be an inadequate estimate of the $k(h)$ and $h(\theta)$ relationship of the upper layer. However the similarity between the measured and estimated moisture content of the lower soil layers allowed the application of SWATRER to the 37 sites. It supported the use of the simulated water supply through capillary rise as a reliable independent variable for the regression analysis.

The results of the regression analysis between the amount of water delivered by capillary rise from the groundwater table up to the rooted horizons and the different growth parameters are summarized in Table 3. S_{00} and S_{10} showed a good relationship to water supply through capillary rise ($R^2 = 0.72$ and 0.74, respectively). This opens perspectives for research into the growth-site interaction, as both growth parameters are commonly used as growth levels (site indexes) in yield tables.

Height, circumference, basal area and volume, especially their values at age 12 years, also showed a high degree of correlation ($R^2 = 0.77$, 0.78, 0.78 and 0.77, respectively). A lowering in percent variation of these growth parameters associated with capillary water supply is possibly due to a better root penetration through the lower soil layers (IICg), through which root development is

TABLE 3

Results of the regression analysis between the water supply through capillary rise from the ground-water table (CR) and the growth parameters

Growth parameter	Regression equation	$R2$*	Root MSE**
S,XJ	*S00* = 21.032 + 0.077 *CR*	0.718	1.701
S10	810 = 6.785 + 0.028 *CR*	0.740	0.585
Hi2	H12 = 8.401 + 0.038 *CR*	0.770	0.721
H1s	H15 = 12.112 + 0.041 *CR*	0.708	0.917
C12	C12 = 22.074 + 0.283 *CR*	0.784	5.220
C15	Cis = 49.456 + 0.286 *CR*	0.739	5.976
G12	Gi2 = -116.446 + 3.068 *CR*	0.778	57.630
Gis	Gis = 40.332 + 4.372 *CR*	0.746	89.507
V12	V12 = -137.189 + 2.275 *CR*	0.766	44.137
Vis	Vis = -120.708 + 4.170 *CR*	0.732	88.620
iH2--s	iH2_5 = 0.496 + 0.006 *CR*	0.474	0.213
iHs-10	iHs-10 = 2.092 + 0.022 *CR*	0.655	0.568
iHn-1s	iH11_15 = 6.081 + 0.011 *CR*	0.375	0.528

*All correlation coefficients are significant at the 0.1% level.
**Mean square error

difficult, with increasing age. Nevertheless, the high R^2 values for circumference, basal area and volume indicate that it might be well worthwhile to develop a girth growth model, taking into account fixed spacing pattem, appropriate to West European poplar cultivation.

Periodic height increment, iH_{2-5}, iH_{6-10} and iH_{11-15}, showed a much lower correlation with the water supply through capillary rise, particularly iH_{2-5} and iH_{11-15}. A possible explanation might be the lower water requirement during the first years after planting, together with partial suppression of the spontaneous vegetation by cultural measures. Also, the sharper mutual competition might affect height growth of the well growing trees in the third growth period. This is in contrast with the slower growing trees, which still have free crowns. Low R^2 values between height increment and capillary rise may also be due to a lag coefficient between growth and water supply. This aspect needs further research. However, water deficit is a determining factor during the whole investigation period and is not restricted to the first years after planting, as shown by the high correlation with height at the age of 12 and 15 years.

CONCLUSIONS

The simulation model for the water balance, SWATRER, is a useful tool in growth-site research. Water supply can be related to yield, as shown by the good correlation between the yield levels 8_{00} and 8_{10} and the water supply through capillary rise up to the rooted zone. Knowledge of the relationship between soil properties and yield is necessary for cost-benefit analysis and land evaluation studies.

As girth growth and basal area showed the highest correlation with water supply, a girth growth model, as far as poplar is concerned, would be a suitable input value for the growth-site relationship. In addition, girth is an easy to measure growth parameter.

However it is very worthwhile investigating some poplar-specific input values of the model, especially the sink term parameters, potential evapotranspiration and interception in relation to crown development and spacing. This should result in the development of a water balance model adapted to growth-site research. Furthermore, this study, showing the possibilities of water balance models for growth-site research, must be a start to further research on a larger scale, i.e. enlargement to other sites and clones, investigation into clone-specific water requirements, water uptake capacities and rooting.

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