TRANSPIRATION OF TWO WILLOW SPECIES (*SALIX VIMINALIS* AND *SALIX TRIANDRA*) GROWING ON A LANDFILL OF DREDGED SLUDGE

SCHEIRLINCK, H., LUST, N. & NACHTERGALE, L.

Laboratory of Forestry, University of Ghent

Abstract

A landfill of dredged sludge was afforested with two different willow species : *Salix viminalis* cv. *Belgisch Rood* and *Salix triandra* cv. *Noir de Vilaine*. Mats of willow wickers of those two species were woven and put on the non-consolidated sludge. Next the stomatal resistance and the transpiration rate of this one year old stand was measured on five characteristic days during the vegetation period. Finally these data were extrapollated over the whole growing season to estimate the total transpiration of this stand. Two different methods to do this extrapollation were compared.

1. Introduction

Dredging waterways becomes more and more important. On the one hand the tonnage of the ships increases, on the other hand the run-off in urbanised regions gets bigger. So to keep ship traffic possible and to protect the land against inundations, in Flanders yearly 4 Millon m^3 of sludge is dredged and dumped on land.

In former days sludge was regarded as a fertiliser and was wanted by the farmers, nowadays however, the sludge contains high concentrations of pollutants which change it into a waste.

In a region with a high population density such as Flanders, the sites were sludge can be dumped are limited. So a justified revalorisation of those sites is required. Afforestation seems one of the best solutions. Because trees intercept and evaporate an important part of the rainfall, the amount of water that percolate and finally can pollute the groundwater is reduced.

In this study the transpiration rate of two willow clones that were planted on a recently filled sludge dump are examined and used as an indicator of the vitality of those young trees.

2. Research and methodology

The research site is located in Menen in Flanders. The sludge that was used in the experiment was dredged out of the Leie, a freshwater river. On the research site a climatological station was operational during the growing season of 1993. Every five minutes following variables were automatically registrated : air and ground temperature (°C), relative air humidity (%), precipitation (mm), short wave insolation (W/m^2) wind speed (m/s) and wind direction (degrees). After three measurements a mean value was calculated and saved in the electronic memory. For the precipitation every day a cumulative sum was calculated. The climatological station also calculated an hourly and daily mean of those values. Regularly the data were transferred to a datalogger (type Campbell CR 10).

Small containers with a content of about 400 m^3 were filled with polluted sludge. The containers were 10m X 20m and had a depth of 2m. The sludge was dredged out of the Leie near Menen and then treated with chemicals adsorbing the hydrophobe particles. When the sludge is aerated intensively, these particles are concentrated in the upper layer of the sludge. Concerning the concentration of heavy metals there isn't much difference between the treated and the non-treated sludge. The amounts of hydrocarbons and polyaromatic carbons though, increase significantly in the upper layer. This sludge was used to fill a container, in which two willow clones were planted in the spring of 1993.

Willow wickers were used to weave mats which were put on the dredged sludge. The mats were about 1.5 m by 1.5 m and had a mesh of 10 cm (Fig. 1). Two different willow species were chosen because this species is easy to reproduce vegetatively and because it is the natural pioneer vegetation on alluvial soils without profile. In one mat two different willow clones *Salix viminalis* cv. *Belgisch Rood* en *Salix Triandra* cv. *Noir de Vilaine* were used.

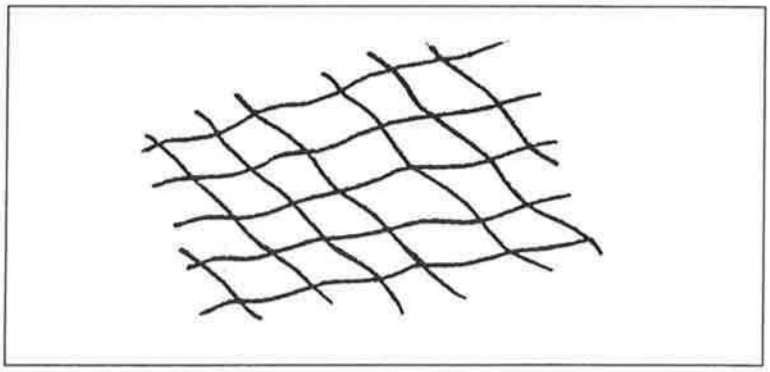


***Figure 1** : Schematic presentation of the mats of willow wickers*

The Leaf Area Index (LAI) was measured 8 times. Each time, 10 young sprouts were harvested and defoliated. The surface of the leaves was measured with a photo-electric measuring unit. The mean value and standard deviation was calculated of the LAI of those ten sprouts. Next a best fit curve through these points was drawn. So an estimated value of the LAI was available for every day of the growing season.

During the vegetation period, the daily pattern of the stomatal resistance was measured on five characteristic days with a porometer (type Mark III). This way the transpiration rate could be calculated. Using these data together with the climatological data of the weather station, the amount of water that was transpirated during the growing season was estimated.

The stomatal resistance was measured on 07/08/93, 16/08/93, 27/08/93, 07/09/93 and 12/09/93. Those characteristic days were spread over the vegetation period to take into account possible changes of the stomatal resistance due to ageing of the leaves. One tried to select two sunny and tree cloudy days as far as it was possible. Sometimes a the day started sunny but later on clouds got up.

The stomatal resistance was measured on the upper side as well as on the underside of the leaves of both willow clones. On each clone six measurements were carried out as follows: on the underside of two sun leaves and two shadow leaves and on the upper side of one sun leaf and one shadow leaf. By the selection of the sun leaves always the fifth or the sixth leaf counting from the top of the sprout was chosen.

During one specific day measurements were carried out on the same leaves. It was impossible to do these measurements on all of the five characteristic days on the same leaves because sun leaves became shadow leaves and because some leaves were attacked by insects. Measurements were done between 9 a.m. and sun set. The stomatal resistance of the leaves was measured every hour. On cloudy days the resistance was bigger and the period between two measurements on the same leave increased to an hour and a half.

The porometer (type Mark III) has a measuring unit and a sensor head. This sensor head has a cup with a humidity en temperature meter and is put on a leaf during the measurement. Dry air was pumped into the cup and the air humidity in the cup was decreased by 5%. The relative air humidity in the cup was going up due to the transpiration of the leaf. When the relative air humidity was 5% higher than the surrounding air humidity, again dry air was pumped into the cup. The time of one cycle, called the transit time, was registrated by the measuring unit. After 3 or 4 cycles this value became constant. A temperature sensor on the underside of the cup registrated the leaf temperature during the measurements.

By means of a calibration curve a stomatal resistance could be calculated out of this transit time. This calibration curve depended on the temperature and the air humidity and was made after every measurement session of the 12 selected leaves. This callibration curve could be discribed by a linear function (Y=aX+b). The constant "a" is specific for the internal resistance of the porometer and therefore the same for each measurement.

The transpiration rate on the five characteristic days was calculated with following formula :

$$E = (d_a.c_p / \gamma.\lambda) \,.\, (e^0_{(Tl)} - e_a) / r_v \qquad \text{(i)}$$

with :
- E : transpiration rate per unit soil surface (g/(s.m))
- $e^0_{(Tl)}$: vapour pressure by saturation at leaf temperature (mbar)
- e_a : vapour pressure of the air (mbar)
- r_v : stomatal diffusion resistance of water vapour (s/m)
- d_a : density of air (1.204 kg/m³ at 20°C)
- c_p : specific heat of air (1010 J/(kg.°C) by constant pressure)
- γ : psychrometer constant (0.658 mbar/°C)
- λ : latent transpiration heat (2454 J/g)

This diffusion law of Fick is analogue to the law of Ohm. The numerator ($e^0_{(Tl)} - e_a$) gives also a difference in potential, this is in vapour pressure ; the denominator (r_v) expresses a value of diffusion resistance. As the leaf temperature is known the vapour pressure by saturation in the leaf can be calculated by means of the following formula:

$$e^0 = \exp\,(52.57633 - 6790.4985/\,T - 5.02808 \ln T) \qquad \text{(ii)}$$

With this formula also the vapour pressure of the air by saturation (e^0_a) could be calculated since the air temperature (T) was registrated by the climatological station. Using the relative humidity (RH) measured by the climatological station, $e_a = RH\, e^0_a$ could be calculated.

The transpiration rate (E) was multiplied by the estimated LAI and a certain time period. The stomatal resistance was measured in the middle of this time period.

Two different methods were used to estimate the transpiration over the total growing season.

The first method is based on the principle that there is a good correlation between the rate of transpiration and the insolation (Hansen 1974, Fredrick et al. 1992). For the five characteristic days a degree of cloudiness was calculated. The sum of insolation on these characteristic days was compared with the minimum and maximum value of this parameter. This minimum and maximum was obtained from the data of the Royal Meteorological Institute. Based on this relation, a percentage of cloudiness could be calculated. Next a relation was searched between this percentage and the calculated transpiration for each characteristic day. A percentage of cloudiness was than calculated for each day of the growing season. The daily transpiration could be estimated using above mentioned relation (i).

The second method is the same as the one used by Kowalick and Eckersten (1984) in their model to simulate the transpiration rate of a plantation of willows for biomass. The base of this model is the equilibrium of the energy balance.

$$R_n = H + \lambda E + S_h \qquad \text{(iii)}$$

with : R_n : net radiation (W/m^2)
H : flux density of sensible heat (W/m^2)
λE : energy used to evaporate water (W/m^2)
S_h : heat accumulated in the soil (W/m^2)

The authors emphasise that this simplified formula is extremely useful. It was assumed that $R_n = 0.649 R_s - 23$ (with R_s = short wave radiation) and $S_h = 0$. This last statement is not completely correct since at the start of the growing season the vegetation doesn't cover the soil completely and a part of the sun heat will be accumulated into the soil. Yet Kowalick and Eckersten concluded that if S_h is equal to 20% of the short wave radiation, the leaf temperature only changes with 1°K.

Following equations were used :

$$\lambda E = (d_a.c_p / \gamma) . (e^0_{(Tl)} - e_a) / r_v \qquad \text{(iv)}$$

and : $$H = (d_a.c_p) . (T_l - T_a) / r_a$$

with : T_l : leaf temperature (°K)
T_a : air temperature (°K)

The parameters in the equation have the same meaning as mentioned above. The water vapour that evaporates out of the crop has to deal with a certain resistance in the air layers above the crop. This parameter is called the crop resistance r_a and is strongly correlated with the height of the crop. Therefore following formula was used:

$$r_a = [\log (x-d) / z_0]^2 / K^2.u_a \qquad \text{(v)}$$

with: u_a : wind speed (m/s)
h : height of the vegetation (m)
K : constant of Von Karman (= 0.4)

d : zero plane displacement (= 0.64h) (m)
z_0 : length of roughness of the vegetation (= 0.13h) (m)

Supposing the energy balance always has to be equilibrated, the leaf temperature of the crop can be determinated by iteration. As starting value, the leaf temperature was chosen 10°C below the air temperature. The leaf temperature was increased with steps of 0.1°C and the energy balance was calculated using the data of the weather station. The iteration was stopped when the leaf temperature was 20°C higher than the air temperature. The leaf temperature which gave the best results to equilibrate the energy balance was used to calculate the transpiration rate.

According to Fredrick (1992) a hyperbolic relationship can be found between the stomatal resistance and the short wave radiation. So a daily stomatal resistance could be estimated during the whole growing season by using the data of the weather station.

During periods with rain, the transpiration was assumed to be zero.

3. Results

The evolution of the LAI during the growing season is given in Fig 2. It shows the measured values as well as the adjusted curves through these points. The LAI reached its maximum at the end of august and was about 7.3.

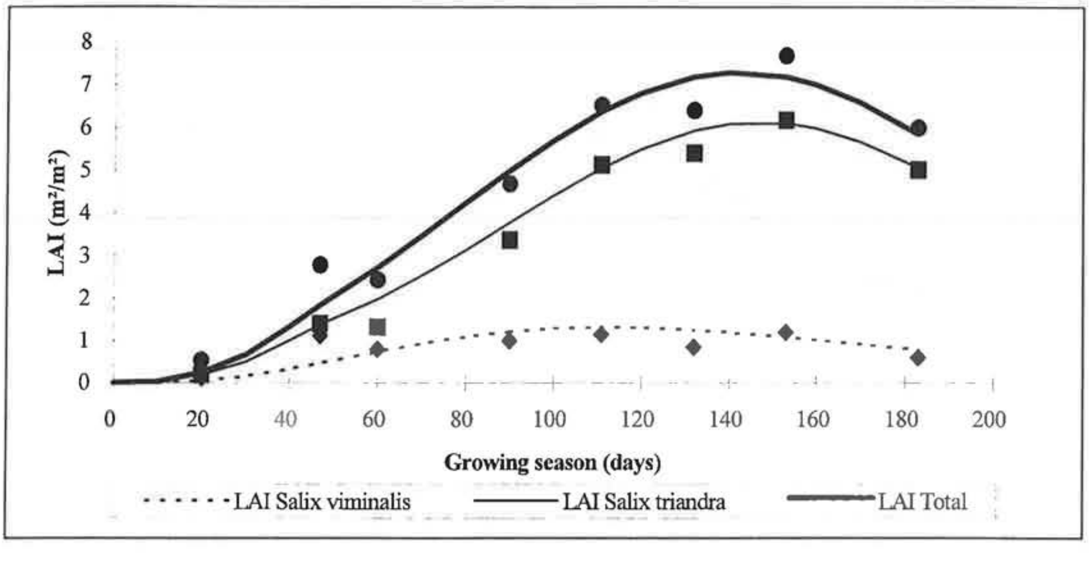


Figure 2 *: The evolution of the LAI of Salix viminalis and Salix triandra (measured values and fitted curves)*

First two characteristic days will be discussed. The first is the characteristic day of 07/08/1993 that was very sunny. The change of insolation and relative humidity on that day is given in Fig. 3. At about 14h00 the insolation reached its maximum value of about 800 W/m². The relative humidity on the other hand was decreasing during the whole day and was at 18h00 about 50% of the maximum value. Fig. 4 shows the evolution of the air and crop temperature. At the time that the insolation reached its maximum the crop temperature was 8°C higher than the air temperature. Later on the day the air temperature decreased and after 19h00 it was a little bit lower than the air temperature. The mean wind speed on the open field was 2.4 m/s. The high stem density and high LAI obstructed air movements in the vegetation so crop temperature rised around noon.

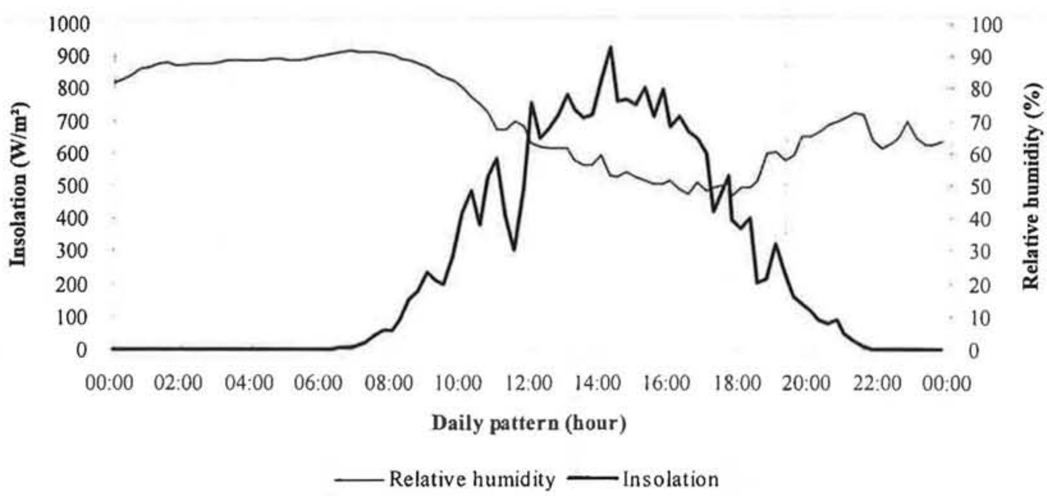


Figure 3 *: The evolution of the relative humidity and insolation during the characteristic day 07/08/1993*

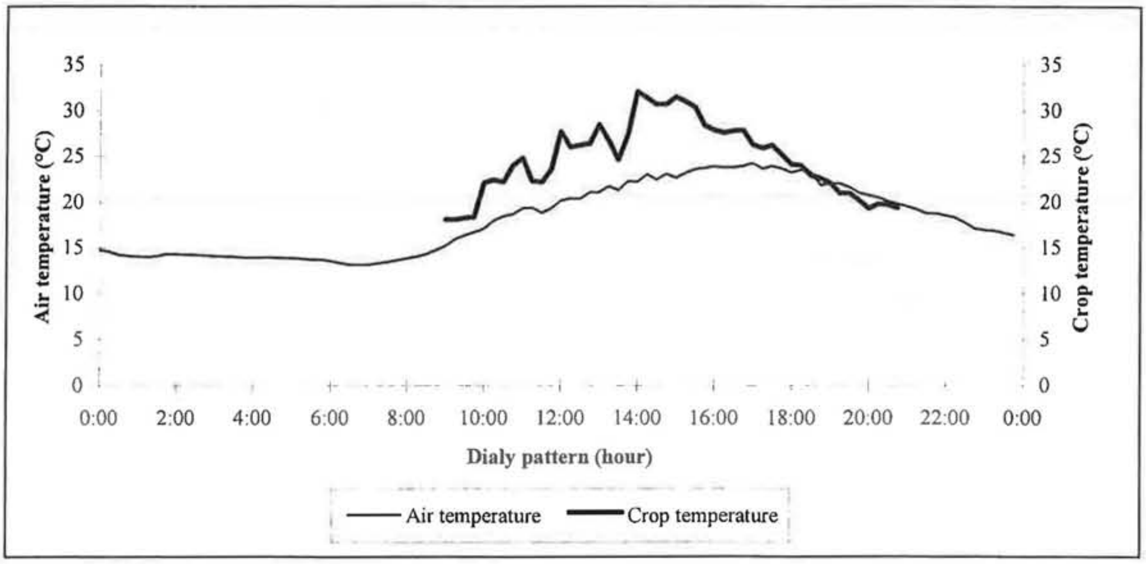
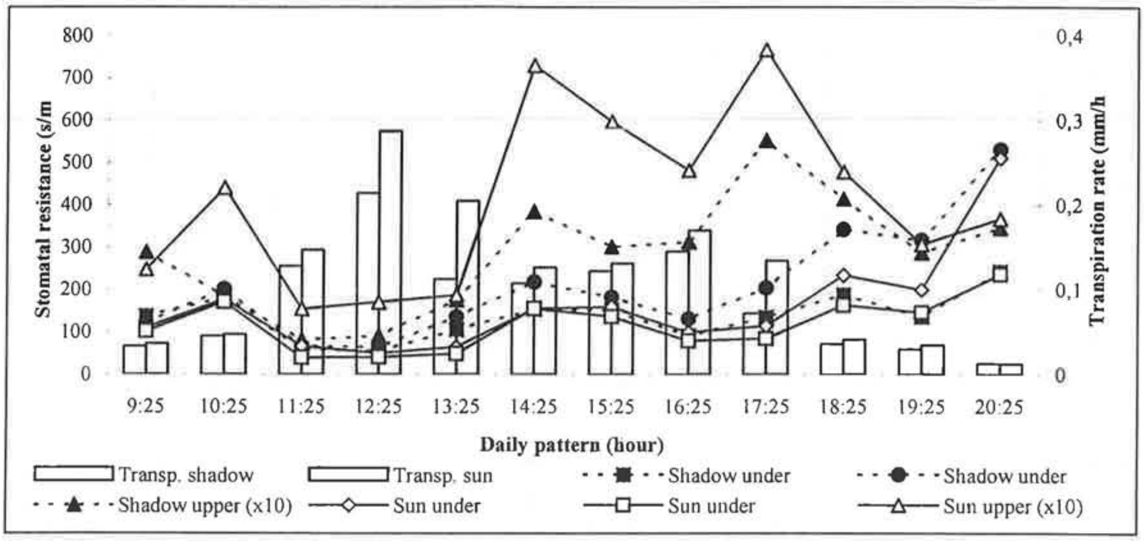
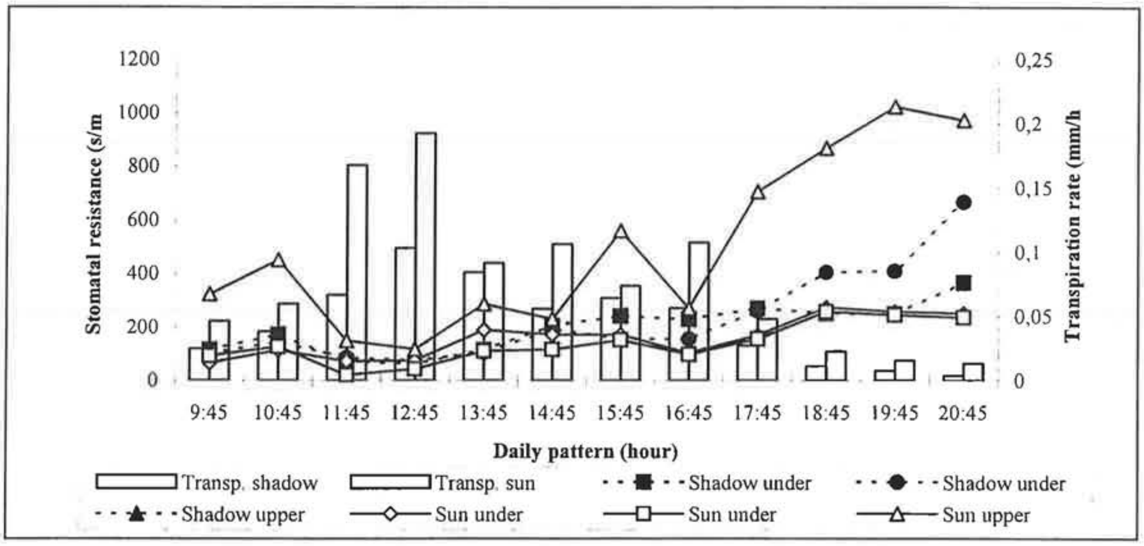


Figure 4 *: The evolution of the air and crop temperature during the characteristic day 07/08/1993*

Fig. 5 shows the stomatal resistance and calculated transpiration of resp. *Salix triandra* cv. *Noir de Vilaine* (a) and *Salix viminalis* cv. *Belgisch Rood* (b). The stomatal resistance is for both willow clones lowest at 12h00. At the moment that the insolation is highest (around 14h00) the stomatal resistance has rised again. This closure of the stoma at noon can be explained as followes: the rate of transpiration is higher then the rate of uptake of water by the roots. This causes turgor losses in the leaves and so the stoma are closing.



(a)



(b)

***Figure 5** : The stomatal resistance of the under and upper side of shadow and sun leaves of Salix triandra (a) and Salix viminalis (b) and the calculated transpiration rate on the characteristic day 07/08/1993*

The stomatal resistance of the upper side of shadow and sun leaves of *Salix triandra* cv. *Noir de Vilaine* is ten times higher then of *Salix viminalis* cv. *Belgisch Rood.* For *Salix triandra* the stomatal conductance fluctuated around 5000 s/m. This value decreased till 1500 s/m around midday. Such high values indicate that there are few stoma on the upper side of the leaves of this species.

The stomatal resistance of the under side of shadow and sun leaves is of the same order and is for the shadow leaves a bit higher then for the sun leaves. Therefore also the transpiration rate of the sun leaves is bigger. At midday the stomatal resistance is for both clones around 100 m/s. The LAI of *Salix triandra* is higher then the LAI of *Salix viminalis* so *Salix triandra* transpirated the most.

The second characteristic day that is discused is the one of 27/08/1993. In the morning the weather was relatively sunny but at 11h00 it became cloudy and the insolation dropped to a level of about 150 W/m² (Fig. 6). The relative humidity during the whole day was high and fluctated between 60 and 75%. The maximum temperature was 16°C (Fig. 7) and the crop temperature was about 4°C higher then the air temperature.

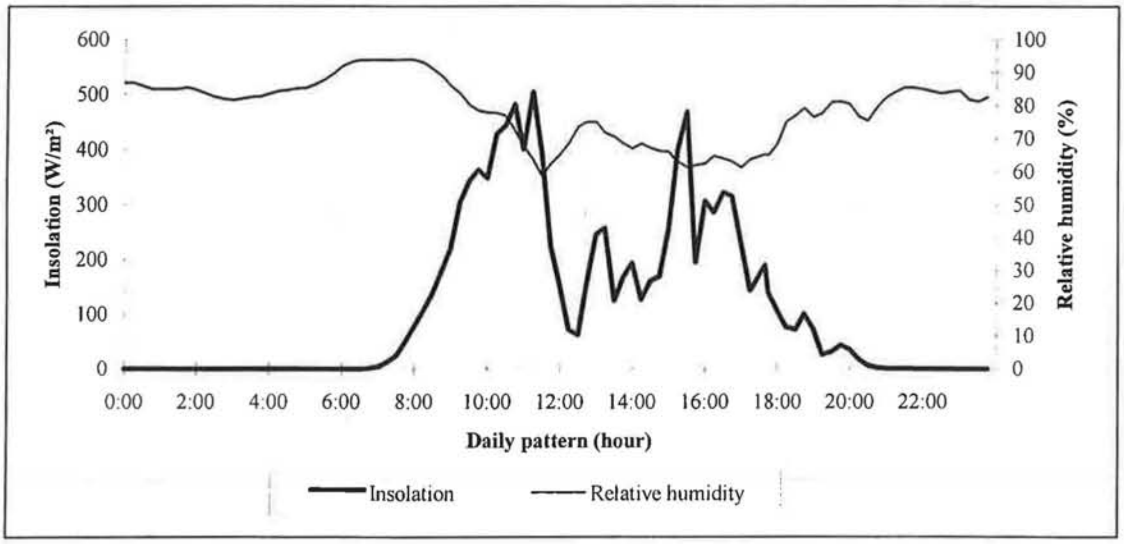


Figure 6 *: The evolution of the relative humidity and insolation during the characteristic day 27/08/1993*

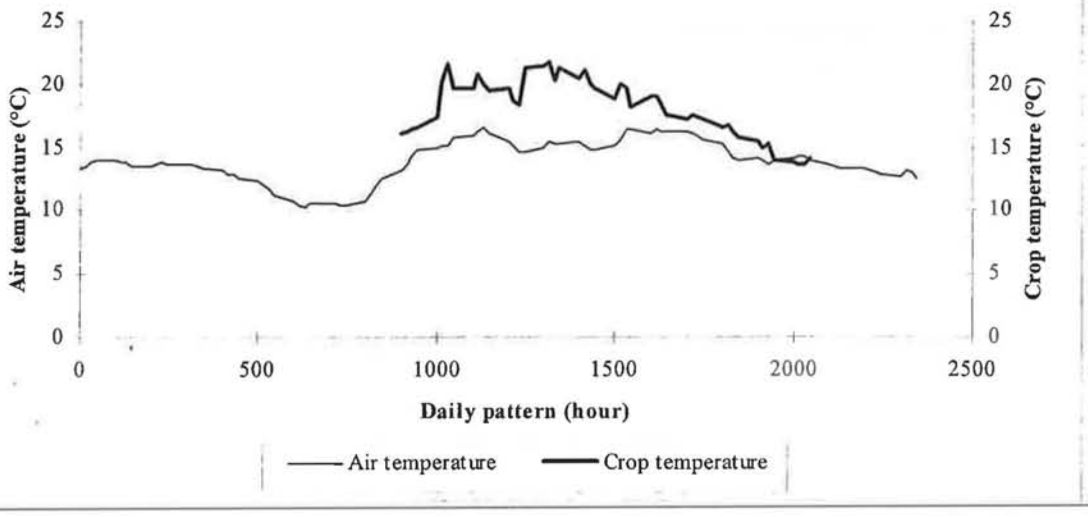
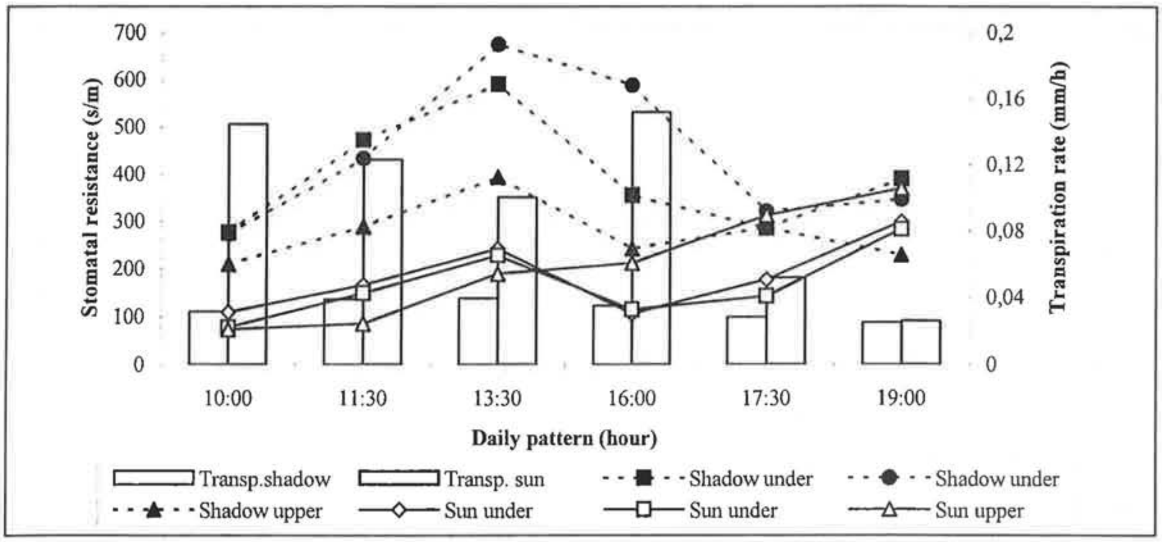
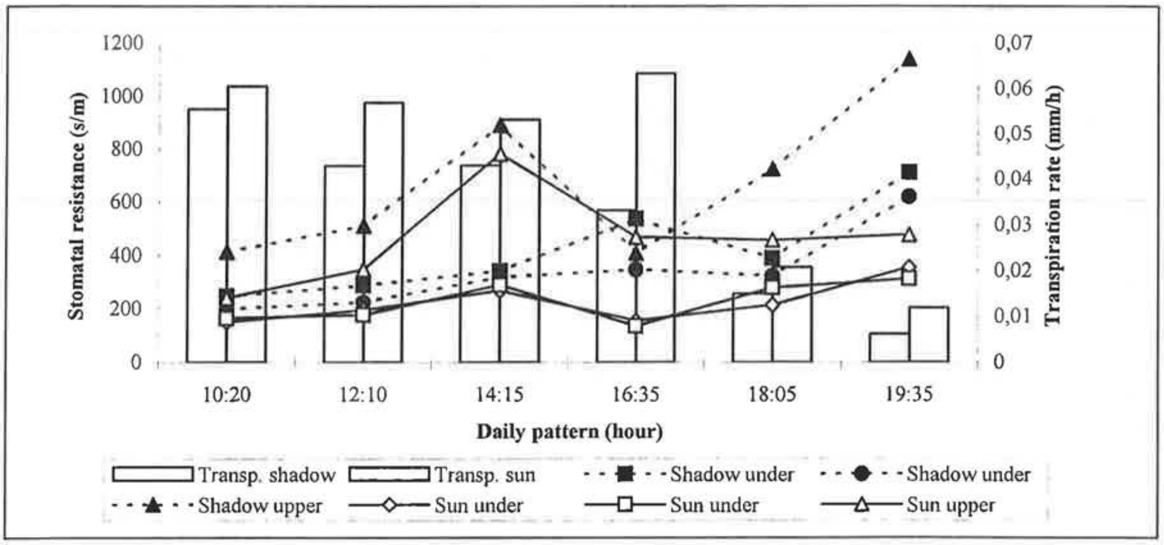


Figure 7 *: The evolution of the air and crop temperature during the characteristic day 27/08/1993*

Because of the high transpiration stomatal resistance could only be measured 6 times that day. Fig. 8 shows that the stomatal resistance of *Salix viminalis* higher is then on 07/08/93. Especially the stoma on the upper side of the leafs are closing by low insolation rates (around 14h00). At about 16h30 the insolation increased and the stoma were opening again. On this cloudy day the transpiration rate of sun and shadow leafs of *Salix viminalis* was approximately the same. This difference was higher with *Salix triandra* (Fig. 8).



(a)



(b)

Figure 8 *: The stomatal resistance of the under and upper side of shadow and sun leaves of Salix triandra (a) and Salix viminalis (b) and the calculated transpiration rate on the characteristic day 27/08/1993*

Table 1 indicates the total amount of water that was transpirated by the two willow clones on the five characteristic days. Values are given for sun and shadow leaves per unit soil surface as well as per unit leaf area index. It was assumed that half of the leaves were sun leaves and the other half were shadow leaves. This is a good approximation for the ratio sun leaves / shadow leaves during the whole growing season.

***Table 1** : The measured transpiration and the degree of cloudiness on the five characteristic days*

Characteristic day	per unit leaf surface (mm / day / m²)				per unit soil surface (mm / day/ m²)			Degree of cloudiness (%)
	Salix triandra		*Salix viminalis*		*Salix triandra*	*Salix viminalis*	Total	
	Sun leaves	Shadow leaves	Sun leaves	Shadow leaves				
07/08/93	0.57	0.44	0.65	0.37	2.44	1.49	3.93	7
16/08/93	0.26	0.12	0.32	0.25	1.00	0.82	1.82	56
27/08/93	0.21	0.07	0.19	0.14	0.80	0.46	1.26	70
07/09/93	0.19	0.18	0.28	0.28	1.05	0.72	1.77	17
12/09/93	0.14	0.07	0.17	0.13	0.62	0.37	0.99	64

Sun leaves as well as shadow leaves of *Salix viminalis* cv.*Belgisch Rood* transpirated per unit leaf surface more then those of *Salix triandra* cv. *Noir de Vilaine* except on 07/08 (a very sunny day) on which the shadow leaves of *Salix triandra* transpirated 17% more and on 27/08 (a cloudy day) on which the sun leaves of *Salix triandra* 10% more transpirated than those of *Salix viminalis*.

The mean transpiration rate per unit leaf surface of the sun leaves of *Salix triandra* is 15% lower then the one of *Salix viminalis* and in comparison to the shadow leaves the difference is 35%.

The total respiration during the whole growing season was calculated in two different ways.

In the first methode a hyperbolic relationship ($Y = a + b/X$) was found between the degree of cloudiness on the characteristic days and the transpiration rate per unit leaf surface that day. The correlation was 0.98 and 0.93 for the sun leaves of respectively *Salix triandra* and *Salix viminalis*. By the shadow leaves the correlation was was 0.73 for *Salix triandra* and 0.72 for *Salix viminalis*.

For the second method the leaf temperature was determinated from the energy balance and than the transpiration was calculated. The stomatal resistance was deduced from the measured insolation based on a hyperbolic relationship that was found between those two parameters.

Fig. 9 shows the cumulative transpiration during the growing season calculated by the two different methods.

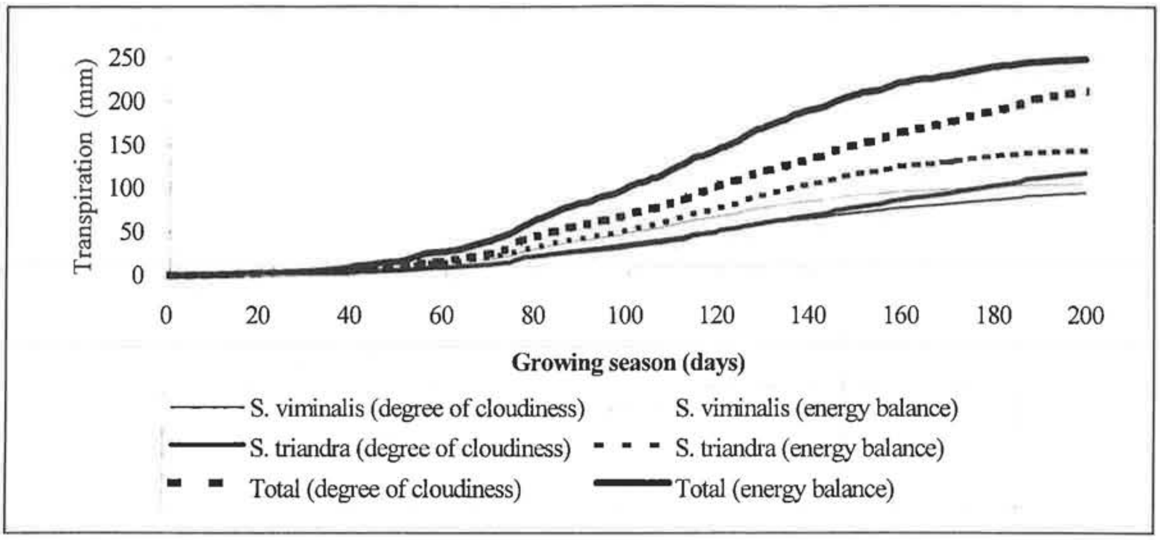


Figure 9 *: The cumulative transpiration during the growing season calculated by the two different methods*

The measured transpiration values of the five characteristic days were compared with the estimated values on those days. So the two simulation methods were checked. The ratios between the estimated and measured values are given in Table 2. A value of 100% means that the estimated and the measured transpiration were equal. The method based on the degree of cloudiness gave an overestimation of 3% and 16% for *Salix triandra* resp. *Salix viminalis*. The total transpiration was overrated by 7%. The big difference between the five characteristic days is reflected in the standard error. This does also apply for the method based on the energy balance. This method overestimated the total transpiration by 20%: the transpiration of *Salix triandra* by 24% and the transpiration of *Salix viminalis* by 15%.

Table 2 *: The ratios between the estimated (two different methods) and measured values*

characteristic day	Method based on the degree of cloudiness			Method based on the energy balance		
	Salix triandra	*Salix viminalis*	Total	*Salix triandra*	*Salix viminalis*	Total
07/08/93	95	118	104	82	99	89
16/08/93	72	76	74	128	106	118
27/08/93	89	122	101	127	134	130
07/09/93	136	122	130	155	125	143
12/09/93	121	141	128	127	113	122
mean	103	116	107	124	115	120
standard deviation	23	21	20	23	13	18

It was assumed that the mean value of the overestimation could be extrapolated over the whole growing season. So the amount of transpirated water that was estimated with the two methods could be reduced to 100%. The results are given in Table 3.

Table 3 *: Simulated and reduced values for both methods*

	Method based on the degree of cloudiness			Method based on the energy balance		
	Salix triandra	*Salix viminalis*	Total	*Salix triandra*	*Salix viminalis*	Total
simulated values	117	95	212	143	105	248
reduced simulated values	108	83	198	110	90	206
standard deviation	27	20	42	33	14	44

The mean value of the reduced transpiration values of both willow clones is similar for both methods : 108 mm and 110 mm for *Salix triandra* and 83 and 90 mm for *Salix viminalis*. So about 200 mm was transpirated during the growing season of 1993. This value is similar to the one that was found by Grip (1981). He measured in Studsvik (Sweden) in a one year old stand of *Salix viminalis* a mean transpiration rate of 198 mm.During July and August very low transpiration rates were measured due to the fact that those two months were very cold and wet. It can be assumed that during a growing season with normal weather conditions about 50 till 100 mm more water is transpirated.Fig. 10 gives the total transpiration and precipitation during the growing season of 1993. It shows also the curve of the precipitation reduced with the intercepted amount of water by the leaves. It was assumed that 0.3 mm water per unit leaf surface was intercepted. So 108 mm of the 382 mm that fell during the whole growing season was intercepted. This amount (28%) is similar to what is described in literature: 25% (Grip 1981) and 30% (Ettala 1988).

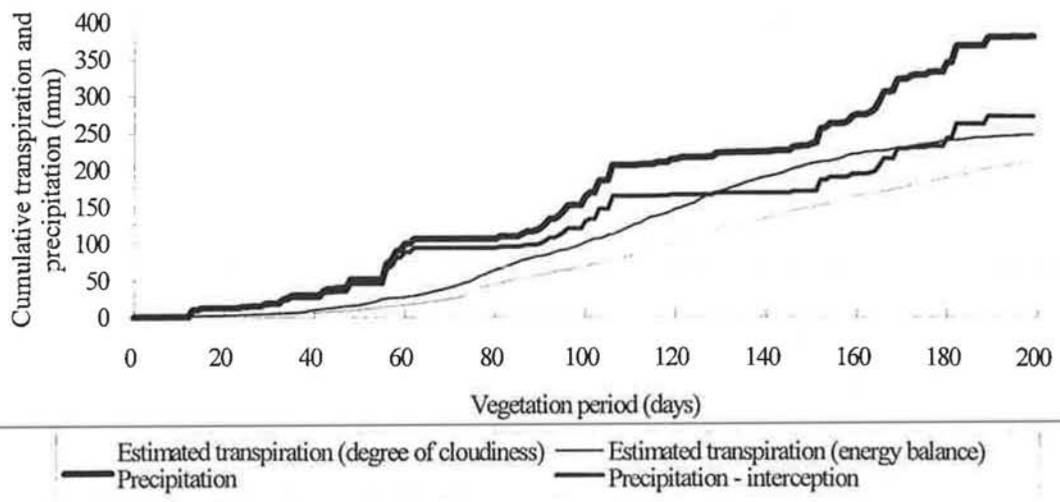


Figure 10 *: The cumulative estimated transpiration (two different methods), precipitation and precipitation minus intercepted precipetation during the vegetation period*

4. Conclusions

The estimation of the transpiration during the whole growing season is a complex matter, because measurements are only carried out on a few days and these results are extrapolated over the whole growing season. Nevertheless, the result of the two different methods that were used seems -after correction- to correspond quite good.

The total estimated transpiration of the growing season of 1993 was not so high (200 mm). The probable reason is not only the bad weather conditions during the summer but also the fact that the calculations were done for a young growing stand. In the following years the leaf area index will reach its maximum value much earlier at the growing season and so the total transpiration will be higher.

The measured values are similar to the ones that are found in the literature. So the polluting elements in the sludge don't seem to have a negative influence during the first growing season of the willow stand.

5. Bibliography

Cermak, J., Jenik, J., Kucera, J. & Zidek, V. (1984). Xylem water flow in a crack willow tree (*Salix fragilis*) in relation to diurnal changes of environment. Oecologia, 64 (2), 145-151.

Cureton, P.M., Groenevelt, P.H. & McBride, R.A. (1991). Landfill leachate recirculation effects on vegetation vigor and clay surface cover infiltration. Journal of environment quality, 20 (1), 17-24.

Ettala, M. (1988). Evapotranspiration from a *Salix aquatica* plantation at a sanitary landfill. Aqua fennica, 18 (1), 3-14.

Frederick, F., Lemeur, R. & Zhang Lu (1992). Test van een Penman-Monteith evapotranspiratiemodel voor de plantafhankelijke controle van de watergifte bij warme kasplanten. Landbouwtijdschrift, 45 (1), 41-56.

Grip, H. (1981). Evapotranspiration experiments in *Salix* stands. Technical report 15, energy forestry project, Swedish University of Agricultural Sciences, Uppsala, 29p.

Hansen, G.K. (1974). Resistance to water flow in soil and plants, plant water status, stomatal resistance and transpiration in Italian ryegrass, as influenced by transpiration demand and soil water depletion. Acta agricultural scandinavia, 24, 83-92.

Kowalick, P. & Eckersten, H. (1984). Water transfer from soil through plants to the atmosfer in willows energy forest. Ecological modelling, 26 (3/4), 251-284.