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Original article

Evaporation and surface conductance of three temperate forests in the Netherlands

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Abstract – This paper shows the behaviour of evaporation and surface conductance for three different forests in the Netherlands: a pine, larch and poplar forest. Maximum evaporation rates of the forests are similar and approach the equilibrium evaporation rates for large extended surfaces. There is a tight relationship between available energy and evaporation for poplars, less so for pine and larch. Average evaporation declines in the order: poplar, larch, pine forest. Observed maximum conductances follow this trend with the poplar having the highest conductance of 55 mm s^{-1}, the larch intermediate with 31 mm s^{-1} and pine the lowest 28 mm s^{-1}. Stomatal control was most strong in the pine forest and less strong in the poplar forest. The conductance of all three forests follows a strong near-linear decrease with humidity deficit until 8–10 g kg^{-1}, with a slowly reducing conductance afterwards. For pine and larch the surface conductance reaches the 50 % reduction value already at solar radiation levels of 150 W m^{-2}, while poplar shows a much less rapid increase. The maximum conductance found here for pine corresponds well with previously published values for the same species. The value for the larch and poplar stand are high compared to other published results. This may be due to the relatively long sampling period of the present study, which increases the likelihood of obtaining rare high values. The results also suggest that at the local to regional scale large differences may be found in forest water use. For predicting water yield of forests at this scale, the local variation in water use and stomatal control will have to be taken into account. (© Inra/Elsevier, Paris.)

surface conductance / stomatal conductance / evaporation / forest stand / scaling

Résumé – Évapotranspiration et conductance de couvert de trois forêts tempérées aux Pays-Bas. Cet article analyse l'évapotranspiration et la conductance du couvert pour la vapeur d'eau de trois peuplements forestiers aux Pays-Bas : pin, mélèze et peuplier. Les taux maximaux d'évaporation sont du même ordre de grandeur et étaient proches de l'évaporation d'équilibre pour des surfaces importantes. Il existe une relation étroite entre l'énergie disponible et l'évapotranspiration pour le peuplier, et moins forte pour le pin ou le mélèze. L'évapotranspiration moyenne des peuplements est la plus élevée pour le peuplier et la plus faible pour les pins. Les conductances maximales de couvert sont rangées dans le même ordre : celle du peuplier montre la plus forte valeur, 55 mm s^{-1}, celle du mélèze une valeur intermédiaire, 31 mm s^{-1}, et celle du pin est la plus faible, 28 mm s^{-1}. Le contrôle stomatique est le plus fort chez le pin et le plus faible chez le

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peuplier. La conductance des trois peuplements montre une forte décroissance linéaire avec le déficit de saturation de l'air jusqu'à environ 8 à 10 g kg^{-1}, puis une décroissance plus lente au-delà. Pour le pin et le mélèze la conductance stomatique atteint 50 % de son maximum pour un rayonnement global de 150 W m^{-2}, alors que le peuplier montre une augmentation moins rapide. Les conductances maximales chez le pin trouvées ici correspondent bien aux valeurs publiées. Celles du mélèze et du peuplier sont élevées par rapport aux données de la littérature. Cela est peut-être dû à la longue durée de la période de mesure de cette étude, ce qui augmente la probabilité d'observer des valeurs exceptionnellement fortes. Les résultats montrent aussi que des différences importantes de consommation en eau par les forêts peuvent être mises en évidence, aussi bien à l'échelle locale que régionale. Pour la prévision du bilan d'eau des forêts, il est nécessaire de prendre en compte les variations locales de consommation en eau et de conductance stomatique. (© Inra/Elsevier, Paris.)

conductance de couvert / conductance stomatique / evaporation / échelle

1. INTRODUCTION

Despite considerable advances in our understanding of forest hydrological processes [26], a number of practical forest hydrological problems do continue to exist in the areas of water and land management. For instance, since the publication of a series of model simulations of water use of typical (model) forest stands for the Netherlands [8], forests on the high sandy soils in the Netherlands have been seen as the prime culprits of the increasing water consumption in these areas. This in turn, has led to plans to replace areas with dark coniferous forests (Douglas fir) with species consuming less water such as oak and Scots pine.

At the same time, technological progress in fast response sonic anemometry, humidity and trace gas measurement (e.g. [23]) has made it possible to routinely measure evaporative fluxes of forests and other vegetation types over prolonged periods of time. This has led to an increase in studies analysing the major vegetational controls on land surface atmosphere interaction at canopy scale [3]. To provide additional information to water resource and land managers in the Netherlands, an extensive project was started, aimed at quantifying the water use of forests by experimental methods. This should provide the observational basis against which the initial modelling estimates could be tested and also provide the basis to obtain parameter values for future modelling [7].

Evaporation can be described by gradient-diffusion theory with two conductances indicating the major controls of water from the vegetation to the atmosphere. The physiologically based canopy, or surface conductance, describes transport from the saturated leaf stomatal surface to the air just outside the leaf. The aerodynamic conductance describes transport from the air outside the leaf to the air at a certain reference height above the canopy. For forest the main control of evaporation is through the surface conductance rather than through the aerodynamic conductance, which is generally an order of magnitude larger. For vegetation with lower height and aerodynamic roughness, the conductances are of similar magnitude or the surface conductance is the larger of the two.

The behaviour of surface conductance in evaporation models can be described by expressing the actual conductance as a maximum conductance limited by a number of environmental factors, such as temperature, solar radiation (or photosynthetically active radiation), atmospheric humidity deficit and leaf water potential or soil moisture [14, 31]. Although, the exact mathematical formulations of the functions differ among authors, the general shape of these functions appears to be broadly similar for various forests [16, 30]. In the observations this maximum value is never obtained, as generally, always some form of environmental stress is present. In this paper the maximum conductance always refers to an observed value.

Several reviews have appeared recently addressing the surprising lack of variation of maximum surface conductance amongst the major vegetation types of the world [16, 17, 28]. Similarly, at the leaf level, Körner [18] found small variation amongst stomatal conductance of vegetation types. The fact that at the local or regional scale large differences in water use of forest may exist, and that at the global scale often all the temperate forests may be described by a few parameters, points to an interesting scale problem, viz. is it possible to use the global compilations of data, averaged for particular vegetation types, to make predictions at the local or regional scale. For practical water management, it is likely that the variation in water use will still be the single most important factor on which management decisions will be based.

The current paper aims to analyse the differences and similarities in evaporation and surface conductance of three temperate forests in the Netherlands. Evaporation rates and surface conductances of the forests will be compared at both seasonal and diurnal time scales and functional dependencies sought. It is the purpose of this paper to seek for generalities on which a useful qualitative comparison can be based, the modelling approach is the subject of another paper.

2. SITE DESCRIPTION AND MEASUREMENTS

The sites are a site of Scots pine on a high sandy soil in the centre of the Netherlands, a larch site on a loamy soil in the North, and a poplar site in one of the polders on a heavy clay soil *(figure 1)*. The characteristics of the sites are given in *table I*. The data quality and methods are described in Elbers et al. [9] and are only briefly summarized here. Fluxes of latent and sensible heat and momentum were obtained by the eddy correlation method from scaffolding towers since early 1995. Only data from 1995 are shown in the current analysis.

The system used consisted of a 3-D sonic anemometer (Solent 1012 R2) and a Krypton hygrometer (Campbell, KH20) linked to a palm top computer (HP-200LX) which calculated on-line variances and co-variances at half hourly intervals using an moving average filter with a time constant of 200 s. An automatic weather station took measurements of incoming and reflected solar (Kipp and Zonen CM21) and long wave (CG1) radiation, soil heat flux (TNO-WS 31 and Hukseflux SH1), windspeed (Vector A101ML), wind direction (W200P) and temperature and relative humidity (Vaisala HMP35A). Soil moisture was calculated from measurements of the dielectric constant of the soil using frequency domain sensors at 20 Mhz (IMAG-DLO, MCM101). Rainfall was measured above the canopy and in the open field with automated tipping bucket rain gauges. Power was supplied by a 12 V battery, connected to a solar panel and a wind generator. At all sites throughfall was measured by a continuously measuring throughfall gauge and a system of 40 rainfall gauges under the canopy, read weekly.

Surface conductance was obtained by inverting the Penman-Monteith equation [equation (1)] using an observed r_a corrected for the difference in momentum and heat transport [33]. The Penman-Monteith equation reads:

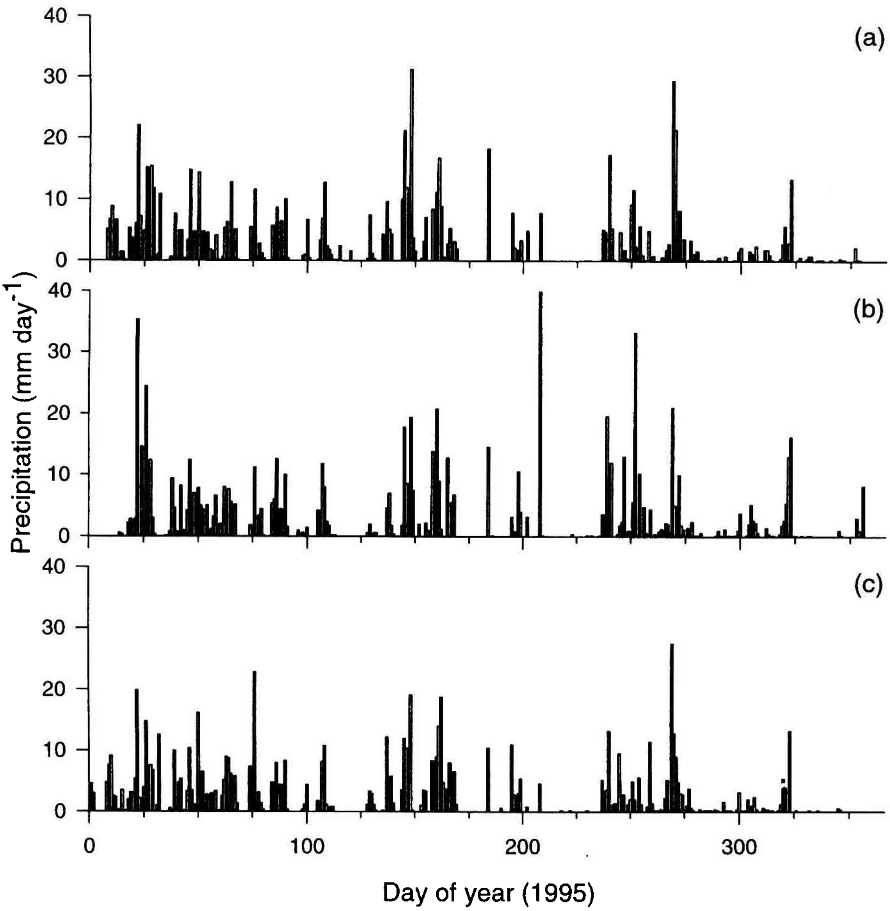


Figure 1. Precipitation for the three forest stands: pine (a), larch (b) and poplar (c).

Table I. Site description.

Site	Loc	Height	z_0	d	Dens.	DBH	LAI	Rain	z_{ref}
Pine	52^0 10' 5^0 44'	15.1	1.5	8.1	360	0.254	3	813	26
Larch	53^0 1' 6^0 24'	22.0	2.4	12.5	300	0.291	2.8	832	27.8
Poplar	52^0 19' 5^0 27'	16.2	1.7	9.1	440	0.247	2.8	697	23.2

z_0, roughness length; d, zero plane displacement height (m), Dens., density of trees ha^{-1}; DBH, diameter at breast height (m); z_{ref}, measurement height fluxes (m); 1995 rainfall (mm).

$$\lambda E = \frac{\Delta(R_n - G) + \rho c_p \delta q\, g_a}{\Delta + \gamma\left(1 + \frac{g_a}{g_s}\right)} \qquad (1)$$

where λE is the latent heat flux, R_n the net radiative flux, G the soil heat flux, g_a the aerodynamic and g_s the surface conductance, Δ the slope of the saturated specific humidity temperature curve, c_p the specific heat of air, ρ the density of air, γ the psychometric constant and δq the specific humidity deficit.

The use of this equation assumes that the source and sink height of temperature and humidity are located at the same height; in the case of an understorey the upper canopy and under canopy are thus lumped together in a single isothermal layer. The surface conductance is in the case of a homogeneous canopy approximately equal to the parallel sum of the stomatal conductances [29]. In practice environmental control on canopy conductance is regulated by the behaviour of the guard cells in the stomata. At the canopy level these controls are lumped together and appear more smooth than when observed at the leaf level. This explains the success of canopy conductance models in single leaf evaporation models.

3. RESULTS

3.1. Measurements and data quality

Overall daily energy balance closure is good [9] and is summarized in *table II*. The recovery ratios, defined as the average energy balance closure for daylight hours, i.e. the ratio of the measured turbulent fluxes over the sum of net radiation and soil heat flux, are close to unity. *Table II* also shows the difference in energy partitioning between the forest with the poplar stand converting most of its available energy into evaporation. The reverse is true for the needle carrying forests which convert most of their available energy into sensible heat. The half hourly data used in this paper were selected for dry days only (minimum 2 d after the last rain), and only those 30 min values were used for which energy balance closure was better than 25 %. The first criterion was used to remove the possibility of contamination of the transpiration flux by soil evaporation. Although some soil evaporation may still occur after 2 d, this is unlikely to be substantial. Data suspicious of dew or wet canopy after rain were also removed from the analysis. This data screening resulted in a data set which thus contained only dry canopy evaporation with minimum or no contamination by soil or wet canopy evaporation. Note that the word evapora-

Table II. Average fluxes of the stands used in this analysis.

Site/Flux	Rn-G	Latent heat	Sensible heat	Recovery ratio
Pine	387 (± 5)	158 (± 3)	229 (± 4)	1.00
Larch	387 (± 8)	178 (± 5)	200 (± 5)	0.98
Poplar	322 (± 8)	212 (± 6)	116 (± 3)	1.02

Values between brackets indicate standard error of the mean, recovery ratio is the quotient of the sum of the turbulent fluxes and the available energy Rn-G.

tion is used to denote both transpiration (i.e. dry canopy evaporation) and soil evaporation, although in practice the terms transpiration and soil evaporation will be used throughout most of the paper. This usage of evaporation is physically more precise and avoids using the more imprecise term evapo-transpiration.

The last selection criterion was used to minimize potential advective or heat storage effects and does not effect, but removes a number of uncertain data values from the analysis. Elbers et al. [9] also perform a source area analysis which suggested that generally during day light conditions fetch requirements were adequate. For the larch forest only those data were selected with sufficiently long fetch, as at this site, a bog covered by *Molinia* borders the forest in a western direction [9].

3.2. Seasonal evaporation and surface conductance

In *figure 2* the average and maximum half hourly transpiration of the three forests is shown. Throughout most of this paper both the average and the maximum values of variables are shown. This gives an indication of the statistical variation in the data, and allows a qualitative assessment of the main functional relationships between conductance and environmental variables. It is clear from this figure that the poplar stand in the polders has the highest average transpiration, followed by the larch. *Figure 2* indicates that the poplar stand transpires close to its maximum rate as the difference between the average and maximum values is generally small. The conductance of forests declines rather smoothly (lin-

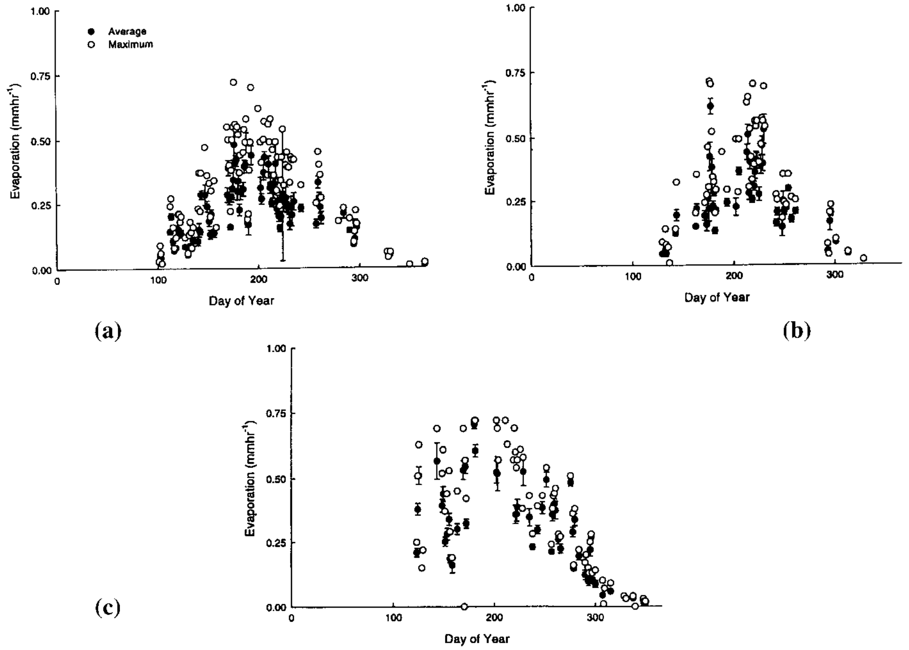


Figure 2. Evaporation rates of the pine forest (a), the larch forest (b) and the poplar forest (c). Maximum rates and average daily rates are given as a function of day of year.

early) after an early morning maximum during the course of the day [30], with no substantial midday closure effects. This suggest that for the two other forests, where the average half hourly transpiration rate is roughly two thirds of the daily maximum, significant stomatal control is present.

The maximum transpiration rates for the three forest are of similar magnitude (0.7 mm h^{-1}). This rate corresponds to the equilibrium evaporation rate with a Priestley Taylor coefficient of unity [21]. Although generally a value larger than unity would be expected [6], the suggestion from these results is that the maximum evaporation rate from vegetated surfaces is controlled by the physics of the boundary layer and less so by plant physiological control mechanisms. Care must thus be exercised in linking maximum evaporation rates to physiological parameters.

During the winter, after day 300, measured evaporation rates are occasionally still of the order of 0.1 mm h^{-1}. Although the data were selected to minimize effects of soil and wet canopy evaporation, this evaporation must be attributed to stem, understorey or soil evaporation. Certainly in the poplar stand some of this evaporation is caused by the soil and dead understorey (litter) as by that time leaves had already fallen off the canopy. This evaporation gives a quantification of the residual, or background evaporation for other periods of the year.

All forests show a steep increase in transpiration in the spring, although the timing is slightly different for each forest. The pine forests start to transpire the earliest, around the beginning of April. Leaves started to grow in the poplar stand from the end of April until mid-June and fell after early September, a process which was fully completed only around mid-October. The larch stand started to grow new needles from mid-April till the end of May and needle fall took place during November. Unfortunately in 1995, only qualitative observations of leaf area development were available. In general it may be expected that evergreen needle leaf forests are able to start transpiring earlier in the season, as they do not first need to grow new needles. This would explain the difference in early spring transpiration between the stands. The relatively high evaporation rates of the poplar stand in the spring are caused by undergrowth of nettles and shrubs which experienced a rapid growth before the leaves started to grow on the trees. This results in the highest total stand evaporation for the poplar stand. The higher values of poplar transpiration around day 250 originate only from the forest canopy, as the undergrowth has died down.

All three forests show a decline in evaporation during the dry period from day 210 to 240. This is most likely due to increasing soil moisture stress and or temperature stress (see below).

In *figure 3* evaporation is plotted against the available energy. The pine forest, on average uses 40 % of the available energy for evaporation, remarkably consistent with values quoted for a Boreal Jack pine stand in Canada [2]. In contrast, the poplar stand uses 66 % of the available energy for evaporation, consistent with the estimates for a broad leaved temperate forest [2]. This difference reflects primarily the behaviour of the surface conductance of both forests, as the roughness length, and consequently the aerodynamic conductance, of the forests are almost similar. The larch forest is intermediate with 46 %. Hinckley et al. [12] note a low atmospheric coupling for a poplar stand in the US. Their result fundamentally agrees with ours, as low coupling to atmospheric vapour pressure deficit as found in their study, would indicate a tight relationship between net available energy and evaporation, with no substantial sensitivity of transpiration to changes in vapour pressure deficit.

Figure 4 shows the seasonal behaviour of the conductance of the three forests. The surface conductance is shown as a daylight average with a corresponding standard error and as a maximum value. There is not always an equal number of points used in the calculation of the average. This limits the approach to showing a general seasonal trend over 1995. Note, that as before, the data were selected to exclude periods after strong rainfall to minimize the inclusion of points when the soil surface, understorey or indeed the forest canopy was still wet.

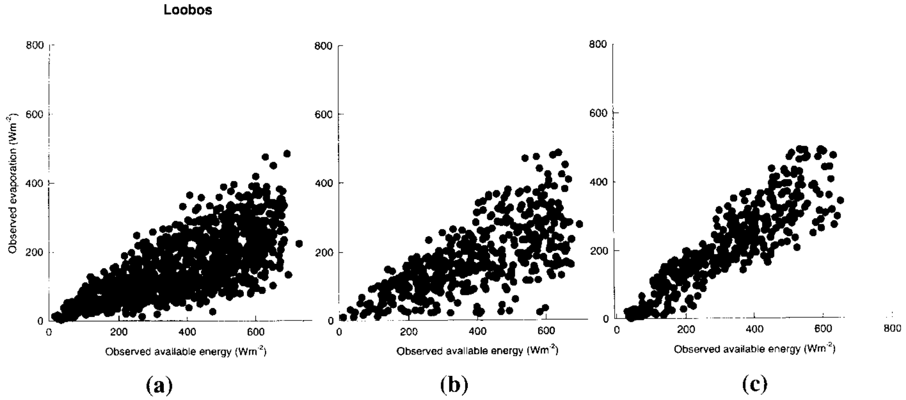


Figure 3. Evaporation as a function of available energy for the pine forest (a), the larch forest (b) and the poplar forest (c).

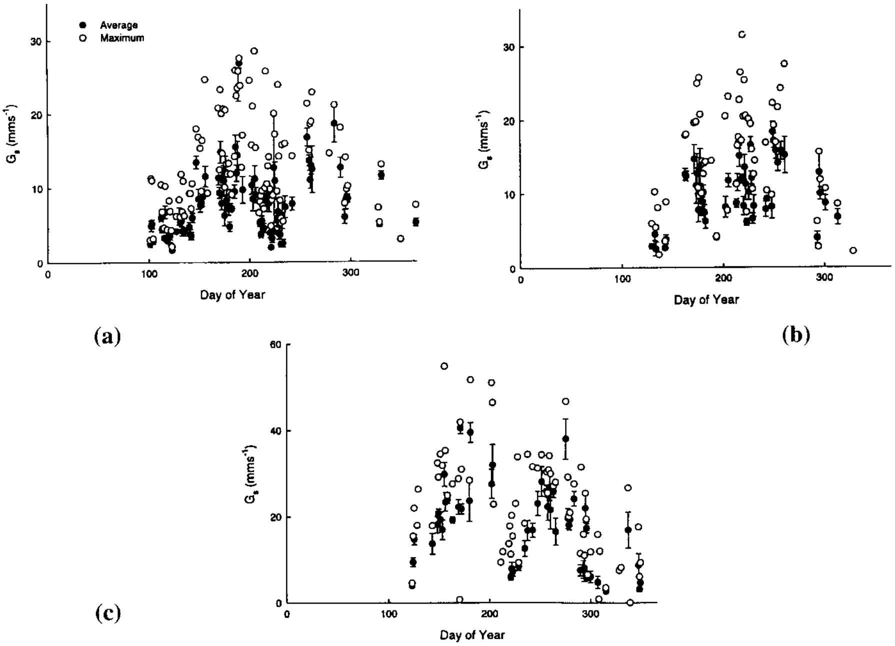


Figure 4. Surface conductances of the pine forest (a), the larch forest (b) and the poplar forest (c). Maximum values and average daily values are given as a function of day of year.

The surface conductance of the poplar stand is generally much higher than that of the Scots pine and larch stand in accordance with the differences in evaporation. The maximum conductance for poplar was 55 mm s^{-1}, for larch 32 mm s^{-1}, and for the Scots pine 29 mm s^{-1}. The average values are much smaller (18, 10 and 7 mm s^{-1}, respectively). The forest stands continue to evaporate, even during the winter season, with an average diurnal residual conductance of the stand of about 2–3 mm s^{-1}. It is possible that this evaporation consists of some residual transpiration, but it is more likely to be caused by evaporation from the litter or soil layer.

In all forests the average diurnal conductance increases around day 150, towards the end of May, and drops after day 200–225, at the end of August, to increase again after day 240. In the case of the poplar stand this is probably caused by temperature stress rather than soil moisture limitation as the ground water level at the site remains close to the surface at 1.75 m. Roots still have access to this reservoir. During this period abnormal high temperatures above 30 °C were regularly observed and plotting conductance against temperature for the poplar (not shown) indicated a sharp decrease in conductance after 25 °C. In the case of the Scots pine forest soil moisture stress is more likely to have caused the decline in conductance and evaporation. This is shown more clearly in *figure 5,* where

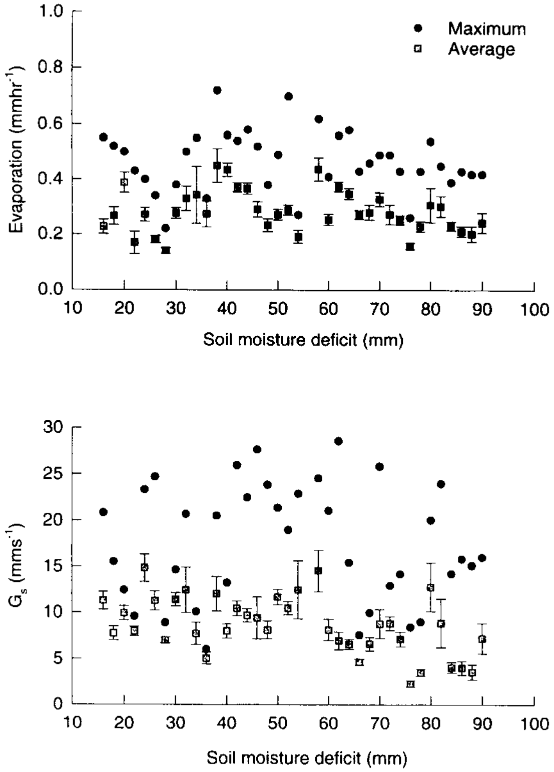


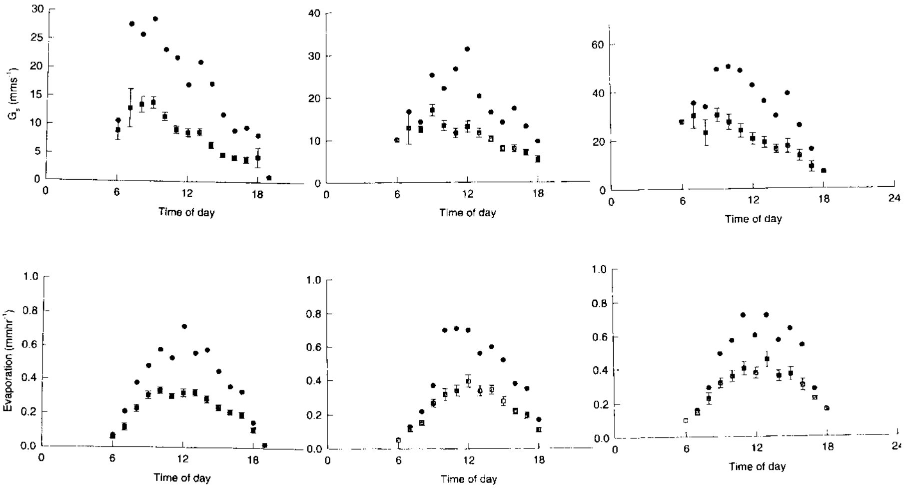
Figure 5. Evaporation (a) and surface conductance (b) as a function of the soil moisture deficit for the pine forest.

evaporation and conductance are seen to be dropping off at moisture deficits above 70–80 mm. This level corresponds to about 50 % of the maximum available water content of the profile.

3.3. Diurnal evaporation and surface conductance

The surface conductance of forests shows a marked diurnal variation, caused to a large extent by its (bulk) dependence on solar radiation and atmospheric humidity deficit [14, 31]. *Figure 6* shows the diurnal behaviour for the three forests of this study. Conductance peaks a few hours after sunrise and after that steadily declines. This is particularly clear in the case of the Scots pine forest, where the maximum conductances are reached at 9 to 10 hours GMT. The larch and poplar stand show a clear maximum in conductance and a less steep decline than the Scots pine. The average conductance of the larch shows relatively little diurnal variation.

The difference between maximum and average conductance can be used as an indication of the amount of stomatal control the trees are able to exert on the transpiration rate. A big difference indicates a large amount of stomatal control. Total absence of diurnal variation in stomatal control would be shown by similar values of the average and maximum conductances. The Scots pine exerts most control on the conductance as the average conductance is generally a factor of two lower than the maximum. The larch stand follows this, but the scatter in the maximum conductances is larger, which makes it impossible to draw firm conclusions. The difference between maximum and average conductance for the poplar stand is smaller, of the order 30–40 %, indicating still substantial stomatal control. The diurnal pattern in conductance and radiation gives rise to marked diurnal trend in evap-



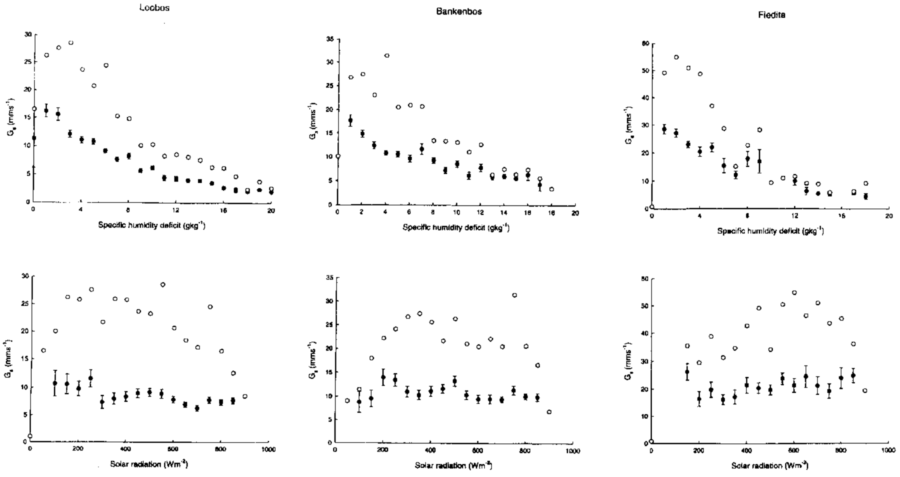
(a) **(b)** **(c)**

Figure 6. Evaporation and surface conductance as a function of time of the day for the pine forest (a, b), the larch forest (c, d) and the poplar forest (e, f).

oration rates with a well-defined maximum at solar noon. This is also shown in *figure 6.*

The diurnal trend in conductance is to a large part controlled by its response to radiation and specific humidity deficit. In *figure 7* the response of the conductance of three forests to specific humidity deficit and solar radiation is shown. *Figure 7* shows that the conductance of pine forests responds most strongly to humidity deficit, with almost complete shut down at 16 g kg^{-1}. The larch forest shows an almost similar but somewhat more gradual response (e.g [1]). The average conductances follow this pattern with less amplitude. The poplar stand also shows a strong fall of conductance in the first part of the curve to a residual conductance of about 5–10 mm s^{-1}. Note, however, that at 8 g kg^{-1} the poplar stand still has an residual conductance of 20 mm s^{-1}, whereas the two needle leaf forests are at considerable lower values. All forests appear to follow a pattern of a relatively strong linear decrease until, say 8–10 g kg^{-1} with a slowly reducing residual conductance afterwards (e.g. [30]). This appears to be a general feature of the humidity deficit–conductance relationship of forests.

Also shown is the response to solar radiation. The pine forest shows a rapid increase with radiation, the 50 % value is reached at 150 Wm^{-2}, the 50 % value for larch being almost the same. For the poplar stand a much less rapid increase in conductance with increasing radiation is observed. It is important to note that the radiation and humidity deficit responses cancel to some extent, as high radiation levels are generally associated with high atmospheric humidity deficits. This explains why the maximum values of all three forest tend to decline again with high radiation (> 600 Wm^{-2}). Both needle leaf forests show a similar response as the forests analyzed by Shuttleworth [30]. The poplar stand is different from these two, as



(a) (b) (c)

Figure 7. Dependence of surface conductance on specific humidity deficit and solar radiation for the pine (a), the larch (b) and the poplar forest (c). Maximum values and average daily values are given.

a steep decline in conductance is observed with humidity deficit, but a somewhat slower response to radiation. Also the decline in conductance with increasing high radiation is less strong than in the other two forests. It is tempting to speculate that this response serves the poplar species well, because it enables it to keep on transpiring, and respiring at higher humidity deficits than other species (e.g. *figure 5*). In the rich clay soils on which it is planted, with large amounts of water available, virtually throughout the year, this behaviour may, although opportunistic, give the poplar the ability for increased gas exchange and consequent rapid growth and wood production.

4. DISCUSSION

The similarity in maximum evaporation rates between forests was recently noted in a review by Kelliher et al. [16]. They also concluded that maximum evaporation rates were likely to be determined by large scale boundary layer phenomena which tend to reduce the sensitivity of forest evaporation to surface conductance. The results obtained in this study support that hypothesis.

The values of maximum conductance agree with previously published values, which are listed in *tables III* and *IV*. Most values are for coniferous forests and generally range from low values for *Picea* species to higher values for *Pinus* species. There is, however, considerable variation in these values, which may partly be explained by the fact that the maximum values do not always refer to the maximum obtained over a complete growing season, but refer to a few special days for which measurements were available. There appears to be no clear relation between leaf area index and maximum conductance; additional leaf area thus does not lead to increased conductance. The average conductance for coniferous forests is 18.7 mm s^{-1} (± 1.2), which compares well with the result obtained by Schulze et al. [28]using a slightly different set of forests. They cite an average conductance of 20 mm s^{-1}. This average number, however, hides large differences both between and within species. For instance the maximum conductance of larch obtained in this study is 31.5 mm s^{-1}, whereas a larch stand on arguably a much poorer soil in Siberia reaches a maximum conductance of only 9 mm s^{-1}. The *Pinus* results show more coherence with an average of 24.1 mm s^{-1}. The value for this study is within the range of these other observed values.

It is unknown how the relatively low values for *Picea abies* of Tenhunen et al. [32] can be explained. Perhaps limited temporal sampling in this particular study may contribute to these low values. The values obtained in this study are at the higher end of the observed values: this may be due to the long sampling period obtained by operating continuous measurements. This will increase the likelihood of obtaining rare high values under specific environmental conditions. It is less likely that they are caused by contamination of the canopy conductance by the soil or understorey. Nevertheless when comparing conductances, the availability of long-term measurements would appear to be a prime requirement.

The value obtained for the maximum conductance of the poplar stand is high compared to the other values published for deciduous forest *(table IV)*. Excluding the current value for poplar, an average of 21 mm s^{-1} is obtained. Including our current measurements yields an average of 26.7 mm s^{-1}. The high conductance for poplar is however consistent with its high water use and quick growth rate (e.g. [12]). Perhaps more important is the relatively strong coupling of transpiration to net available energy *(figure 2)* and its stomatal control *(figure 7)*.

Table III. Maximum conductances for a number of coniferous forest stands.

Coniferous forest	Location	Lat/Lon	LAI	Soil	G_s	Reference
Larix	Veenhuizen, NL	53 00 N 6 24 E	2.8	sand on loam	31	this paper
Larix gmelinii	Yakutsk	61 N 128 E	2.5	silt loam	9	Kelliher et al. [17]
Pinus silvestris	Jadras, S	60 49 N 16 30 E	2–2.6	sandy	19	Lindroth [20]
Pinus silvestris	Thetford, UK	52 25 N 0 40 E	2.7	clay	20	Stewart [31]
Pinus Silvestris	Kootwijk, NL	52 10 N 5 45 E	3	sand	28	this paper
Pinus pinaster	Estampon, Fr	44 5 N 0 5 W	2.3	sand/clay	28	Gash et al. [10]
Pinus sitchensis	Rivox, Sc.		12	peat	25	Milne [22]
Picea abies	Weiden Brunnen, Germ.		5		9	Tenhunen et al. [32]
Picea abies	Coulissenhieb Germ.		7.5		6	Tenhunen et al. [32]
Picea abies	Velen, S	58 48N 14 19E	5		26	Lindroth [20]
Picea abies	Ulborg	56 17 N 8 26 E	5	sand	10	Jensen and Hunnelshoj [15]
Pseudotsuga menziesii	Garderen, Nl		8–11	loamy sand	16	Bouten [5]
Pseudotsuga menziesii	Dunsmuir Creek	49 02 N 124 12 W	1.5	sandy loam	15	Price and Black [27]

Table IV. Maximum conductances for a number of deciduous forest stands.

Deciduous forest	Location	Lat/Lon	LAI	Soil	G_s	Reference
Quercus rubra	Harvard, USA	42 54 N 72 18 W	3		22	Schulze et al. [28]
Quercus rubra	Ede, NL	52 02 N 5 45 E	4.9	sand	27	Ogink-Hendriks [25]
Nothofagus fusca	Maruia, NZ	42 12 S 172 15 E	7 (max)	loam	29	Hollinger et al. [13]
Quercus alba	Oak Ridge, USA	35 57 N 84 17 W	4.9	clay	13	Verma et al. [34]
Quercus petraea	Vienna, Austria				14	Bernhofer and Gay [4]
Populus robusta	Zeewolde, NL	52 19 N 5 26 O	2.8	clay	55	this paper

The results obtained in this study suggest that maximum evaporation rates may be determined more by large scale processes of the atmospheric boundary layer than by canopy conductance. At least this provides an upper limit to the estimation of water use of forest canopies. Generally, however, stomatal control will tend to reduce the transpiration rates, as is evidenced by the difference between the average and maximum behaviour of the conductances. Stomatal control was found to be strongest for coniferous forest, particularly the pine forest. It is worth noting that the amount of stomatal control cannot be explained simply by height of the canopy or momentum roughness length *(table I)*.

The results suggest that at the local to regional scale large differences may be found in forest water use. For predicting water yield of forests at this scale, the variation in water use and stomatal control will have to be taken into account. The large variation in maximum conductances found amongst and between species is an indication of the amount of possible error involved in using average values for coniferous forest as a group. It would appear that for a good prediction of maximum conductance also other factors such as soil nitrogen and carbon content may have to be taken into account. Similarly climatic stress may explain some of the variation in these results.

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