Model development of the water balance of first year *Tilia* (*Tilia europaea ‘Pallida’* L.) grown in ‘Dutch U system’

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Preface

This report is the result of my master thesis performed at Plant Production Systems. The water balance of a new cultivation system of avenue trees was determined and a model of the water balance was developed. The research was performed in cooperation with Plant Research International and the Applied Plant Research (nursery stock). The groups were represented by Peter Leffelaar, Annette Pronk and Henk van Reuler, respectively. I would like to thank the involved supervisors for their help during my thesis research and writing.

Besides I want to thank some other people as well. I would like to thank Ton Baltissen for the information he provided. Furthermore I appreciated the help of Peter van der Putten. He provided the sun scan probe, gave explanation about the usage of the sun scan probe and he read out the data files, for which I would like to thank him. And especially I would like to thank Florian Stöckl, since he helped me a lot during the performance of many measurements.

Summary

Due to upcoming legislation with respect to emissions of nutrients, pesticides and water, a new cultivation system of avenue trees was developed: the ‘Dutch U system’. Instead of growing the trees in the soil, the trees are grown in the substrate filled ‘Dutch U system’. The aim of the current research was to determine and model the water balance of *Tilia europaea ‘Pallida’* L. grown in this system. Such a model would be very useful to explore the opportunities to reduce the water use and nutrient emissions during the cultivation of avenue trees, and with the help of the model, irrigation can be automated in future. The developed model calculates the interception of light, increase of LAI, evapotranspiration, water lost by drainage and the change in the amount of water in the substrate. The model was based on the experimentally determined water balance. The determined and simulated water balance were compared. The model was not validated over different years. The model simulated the water balance well. Evapotranspiration of the months July and August was underestimated 4% by the model. Consequently, drainage was overestimated. A sensitivity analysis was performed and revealed that the model was robust to changes in the parameters and input variables. Simulated evapotranspiration was most sensitive to relative humidity and the predicted crop coefficient. Due to automated irrigation, the application of irrigation water was reduced by 25% compared to the experimentally determined water balance. However, the model needs to be developed further, especially the parts of evapotranspiration and input of water by precipitation.

1. Introduction

Due to environmental legislation with respect to water quality, the project ‘Teelt de grond uit’ (a project about new cultivation systems for (avenue) trees) was started in 2008 (van Reuler and Baltissen, 2010). The aim of the project was to design profitable cultivation systems for avenue trees, having minimal nutrient- and pesticide emissions (van Reuler and Baltissen, 2010). Therefore, a new system was developed: the avenue trees were grown in the substrate filled ‘Dutch U system’. Emission reduction as compared to soil cultivation was obtained by the recycling of drainage water and a better control of growing conditions. Due to growing in ‘Dutch U system’ the environmental impact of pesticides was reduced by 38% to 95% (Baltissen, 2011). Nutrient emissions were also reduced, and could be reduced even more by the reuse of drainage water. Next to the reduction of emissions, some other advantages of the ‘Dutch U system’ are: improved labour conditions, a higher quality of the end-product, a higher production, and a lower plant failure (van Reuler and Baltissen, 2010; Baltissen, 2011). A big disadvantage of the system is the higher investment costs. Although the water was apparently used more efficiently (Baltissen 2011), the water balance of the ‘Dutch U system’ was still not fully closed. To reduce nutrient emissions even more and to be able to develop a sound future irrigation advice, it is important to understand the water balance. Thus further research is still needed to improve the system. A model of the water balance will be useful to explore the different possibilities to reduce the use of water and to reduce the emissions of nutrients of the ‘Dutch U system’.

The water balance of the cultivation system is defined by the water in- and outputs, and can be described by equation 1 (Lal, 1991):

Equation 1: $S = P + I - ET - D - R$, [all, L of water m^{-2} of substrate]

Where S is the change in the storage of water in the substrate, affected by the input of water into and output of water from the substrate. Water input comes from P and I, where P is precipitation and I is irrigation. Water output is caused by ET, D and R, where ET is evapotranspiration, D is drainage and R is runoff. Precipitation can be stored (partly) on plant leaves. The part of the rainfall that is stored on the leaves, and therefore does not reach the soil surface, is called interception (Shachnovich et al., 2008; de Jong and Jetten, 2007). In case of the water balance, only the percentage of precipitation reaching the soil surface (substrate) is counted as input of water. The crop (and weeds) will take up water from the substrate to transpire (T). Besides, water will evaporate from the substrate (E). Together these two factors form the evapotranspiration (ET) (Lal, 1991). The two other flows of output of water from the substrate, namely D and R, are of less importance, because drainage water will be stored outside the ‘Dutch U system’ (evaporation is not possible, since the water is stored in a closed box) and will be recycled (amount of drainage water will be measured), while runoff will not occur due to the flat and edged substrate. For this reason, these two flows will not be addressed additionally in the introduction. At the end, all flows combined will result in a water balance of the substrate of the ‘Dutch U system’.

In the coming paragraphs the different parts (in- and output) of the water balance will be explained in more detail. Each paragraph will deal with a different in- or output.

Storage capacity substrate The amount of available water in a soil is determined by field capacity and wilting point of the soil (Allen et al., 1998). “Field capacity is the amount of water a well-drained soil can hold against gravitational forces” (Allen et al., 1998). Wilting point is reached when plants are not able to take up any water from the soil, due to the low water content. At this point the forces to retain the water in the substrate are compatible to the root extraction capability (Michel, 2010). Compared to mineral soil, wilting point and field capacity of peat substrates (organic substrates) are reached at lower pF values. Peat substrates are not able to retain additional water at pF = 1, so if more water is applied drainage occurs (Michel, 2010; Brückner, 1997). Wilting point is reached at pF = 2 (Michel, 2010; Brückner, 1997). In case of substrate easily available water (EAW, the water a plant easily can extract from the soil/substrate) is retained between the pF values of 1 and 1.7 (Michel, 2010), an EAW content of 40 Vol. % is considered as optimal (Brückner, 1997). Brückner (1997) found out that due to 20% compaction of substrate, the EAW content was decreased by 3 Vol. %.

Precipitation Depending on characteristics of tree-stand and rainfall, a part of the rainfall will be intercepted by the tree canopy (Shachnovich et al., 2008). If the plant surfaces are wetted beyond their water storage capacity, the water will reach bit by bit lower plant surfaces, by the end resulting in a part of precipitation that reaches the soil (de Jong and Jetten, 2007). The amount of water that does not reach the soil surface is called interception. The percentage of precipitation reaching the soil surface, directly or via the tree canopy, is throughfall and stemflow and forms together the net precipitation. The percentage of interception of precipitation depends largely on plant species and precipitation intensities (Shachnovich et al., 2008; de Jong and Jetten, 2007). Due to plant development and increasing leaf area index (LAI), net precipitation differs over the season (Shachnovich et al., 2008; Snow et al., 1999; de Jong and Jetten, 2007). The storage capacity of trees depends on the canopy architecture and LAI, but is generally less than 2 mm (de Jong and Jetten, 2007). In case of large Fagus trees, the maximum interception of precipitation was almost 1 L of water m^{-2} of leaf (Staelens et al., 2006). Net precipitation could be a smaller percentage of the gross precipitation in case of the ‘Dutch U system’ compared to the normal soil cultivation, because the crop canopy can exceed easily the width of a row of the ‘Dutch U system’, -in particular later in the season -, and throughfall will fall next to the rows of the system. Throughfall next to the substrate is not taken into account as net precipitation input in the ‘Dutch U system’. The percentage net precipitation (throughfall + stemflow) entering the substrate will probably differ between species, because crop architecture can influence the distribution of precipitation (fig. 1.).

Evaporation and transpiration During evaporation liquid water is converted into water vapour which will be removed from the evaporating surface (Allen et al., 1998). The driving force of evaporation is the difference between vapour pressure of the surface and surrounding atmosphere, the so called vapour pressure deficit (VPD). Due to evaporation, the VPD nearby the evaporating surface will decrease. However, VPD could be maintained due to air movement/replacement caused by the wind (Allen et al., 1998). In case of the water balance, soil is the evaporating surface. Main energy source to convert liquid water into water vapour

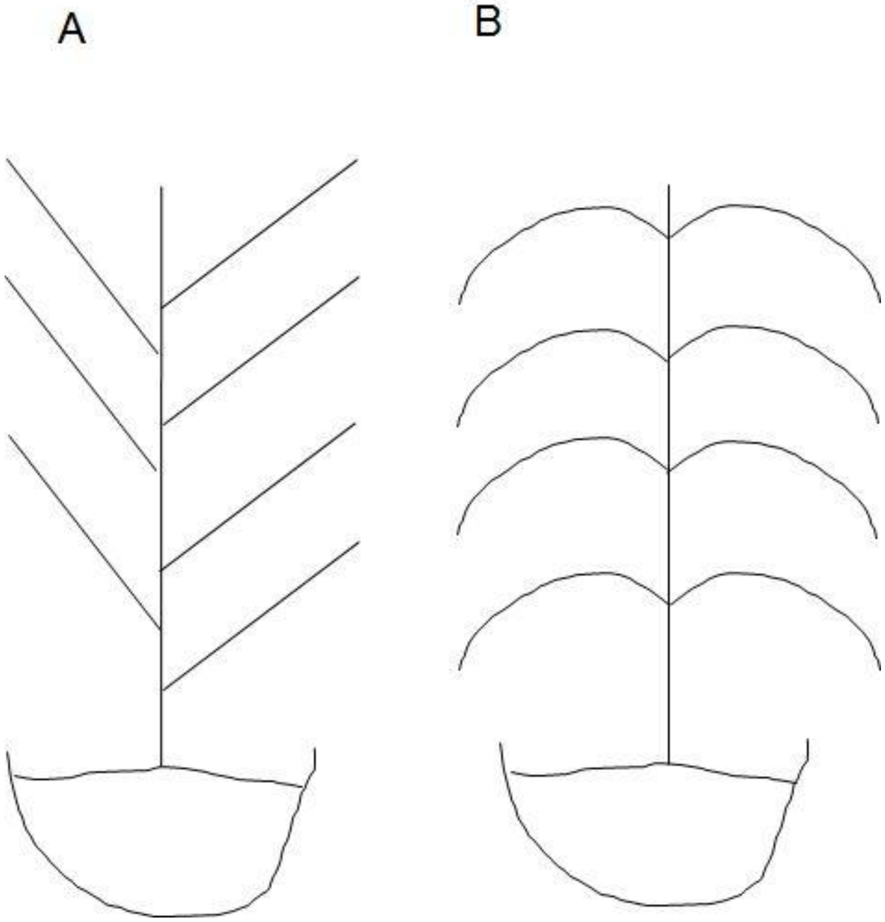

Fig. 1. Two different types of plant architecture, affecting net precipitation input into the substrate. Precipitation will mainly fall into the substrate by a crop with canopy structure A (it catches the precipitation), while due to crop canopy structure B also a part of the throughfall will fall next to the substrate. Therefore, net precipitation into the substrate is expected be higher for a crop with canopy structure A than for a crop with canopy structure B.

is direct solar radiation. Therefore, due to crop/canopy development, evaporation, as part of evapotranspiration is decreasing during the growing season (Allen et al., 1998; Derkx, 2011; Beeson jr., 2010). The combination of the VPD, the characteristics of the energy source and the wind action, will determine the rate of evaporation. Transpiration is the process were water from plant tissue will be vaporized to the atmosphere (Allen et al., 1998; Lal, 1991). Water is mainly lost through the stomata, which will be opened for gas exchange. Gas exchange is needed to maintain carbon dioxide level in the leaf tissue. For this reason, the relationship between transpiration and dry matter production is mostly linear (Lal, 1991). Depending on the circumstances, like low soil water availability, the plant can regulate the opening of the stomata to reduce transpiration. In this way the water loss is reduced, but consequently the production of dry matter is decreased by the lower rate of photosynthesis as well.

Evapotranspiration (ET) is the sum of the water leaving the system by evaporation (E) from the soil and transpiration by the crop (T) (Allen et al., 1998; Lal, 1991). Because ET is the sum of E and T, the rate of ET depends on for example crop type, variety, developmental stage of the crop, soil characteristics and weather circumstances (Allen et al., 1998; Nandagiri and Kovoor, 2005; Derkx, 2011).

An evapotranspiration model Many empirical methods to estimate ET are used in studies related to hydrology, climate and agricultural water management (Allen et al., 1998; Nandagari and Kovoor, 2005). Estimation methods used are e.g. the methods of Penman-Monteith, Makkink and Priestley-Taylor (Derkx, 2011; van Kraalingen and Stol, 1997). The physically based Penman-Monteith method is recommended to be used by Nandagiri and Kovoor (2005) and Allen et al. (1998). The Penman-Monteith equation calculates on basis of weather data the evapotranspiration of a reference crop (ET_0), namely grass. Assumed characteristics of the grass crop are; a homogeneous closed canopy with a height of 0.12 m, a surface resistance of 70 s m^{-1} and an albedo of 0.23 (Allen et al., 1998). By combining the Penman-Monteith equation with the aerodynamic- and surface resistance equations (for grass), the FAO came up with the simplified FAO Penman-Monteith equation (Allen et al., 1998, Pp.24) (equation 2). An equation which was able to predict ET_0 correctly in a wide range of different climates, as was shown by different studies performed in different locations in Europe and United states (Allen et al., 1998).

equation 2: $ET_0 = \frac{0.408\Delta * (Rn - G) + \gamma\left(\frac{900}{T+273}\right)u2 * (es - ea)}{\Delta + \gamma(1 + 0.34u2)}$

where

ET_O reference evapotranspiration [mm day^{-1}],
R_N net radiation at the crop surface [MJ m^{-2} day^{-1}],
G soil heat flux density [MJ m^{-2} day^{-1}],
T mean daily air temperature at 2 m height [°C],
u_2 wind speed at 2 m height [m s^{-1}],
e_s saturation vapour pressure [kPa],
e_a actual vapour pressure [kPa],
e_s - e_a saturation vapour pressure deficit [kPa],
Δ slope vapour pressure curve [kPa $°C^{-1}$],
γ psychrometric constant [kPa $°C^{-1}$]

To derive equation 2 different calculations were made:

$0.408 = \frac{1}{\text{latent heat of water vaporization } (\lambda)}$ [kg MJ^{-1}]

$\lambda = 2.45$ [MJ kg^{-1}]

$0.34u_2 = r_s / r_a = \frac{70}{208/u2}$ [-]

- r_s = surface resistance [s m^{-1}]
- r_a = aerodynamic resistance [s m^{-1}]

$\gamma * \frac{900}{(T+273)} * u_2$ [mm $^oC^{-1}$ day^{-1}]

$\gamma * \frac{900}{(T+273)} * u_2 = \frac{Cp * \rho a}{ra}$ (Allen et al., 1998, pp. 26)

where

$C_P = \frac{\gamma * \varepsilon * \lambda}{R}$ [MJ kg^{-1} $^oC^{-1}$]

$\rho_a = \frac{P}{Tkv * R}$ [kPa kg kJ^{-1} = kg m^{-3}]

$T_{kv} = 1.01\ (T+273)$ [K]

$\frac{CP * \rho a}{ra} = \frac{\gamma * \varepsilon * \lambda}{1.01 * (T+273) * R * 208} * u_2$ [MJ m^{-2} $^oC^{-1}$ s^{-1}]

where

C_P specific heat at constant pressure [MJ kg^{-1} $^oC^{-1}$]
ρ_a mean air density at constant pressure [kg m^{-3}]
ε ratio molecular weight of water vapour/dry air = 0.622
λ latent heat of vaporization [MJ kg^{-1}]
R specific gas constant = 0.287 kJ kg^{-1} $^oK^{-1}$
P is air pressure [kPa]

$\frac{CP * \rho a}{ra} = 86400 \frac{\gamma * 0.622 * \lambda}{1.01 * (T+273) * 0.287 * 208} * u_2$ [MJ m^{-2} $^oC^{-1}$ d^{-1}]

And because the numerator was divided by **λ**, this part results in.

$\frac{CP * \rho a}{ra} = \gamma * \frac{900}{(T+273)} * u_2$ [mm $^oC^{-1}$ d^{-1}]

Allen et al. (1998) indicated that the proposed FAO Penman-Monteith equation estimates ET_O closely. To come up with the evapotranspiration of another crop (ET_C), a crop coefficient (K_C) is needed (Allen et al., 1998). K_C relates the ET_C to the estimated ET_O.

Equation 3: $ET_C = ET_O * K_C$

'The K_C factor serves as an aggregation of the physical and physiological differences between crops and the reference definition' (Allen et al., 1998). K_C values are depending on various variables like the developmental stage of a crop, crop growth during the season and the orientation of the field (Derkx, 2011), so K_C can change over the growing season. Weather conditions are also affecting ET_C, but the weather variability is included in the calculation of ET_O.

ET_O is calculated, assuming a homogeneous closed canopy, while nursery trees (also the avenue trees grown in the 'Dutch U system') do not fit to these assumptions (Derkx, 2011). The more open canopy of nursery stocks do have a higher transpiration, because the amount of net radiation captured and utilized by the nursery plants is relatively high compared to an uniform crop canopy (Irmak, 2005). Alfalfa is accepted as reference crop as well (Allen et al., 1998), and is referred as a tall reference crop; having an increased roughness whereby the aerodynamic effect on evapotranspiration becomes more important (Allen and Pereira, 2009; Koerselman and Beltman, 1988). Because of the larger aerodynamic effect, alfalfa is more suitable than grass to estimate evapotranspiration of the *Tilia* trees grown in the ‘Dutch U system’. The aerodynamic effect is large in case of the trees grown in the ‘Dutch U system’, because of the height and openness of the canopy (due to the elevated cultivation in rows). Assumed crop characteristics of alfalfa are a height of 0.5 m, a surface resistance of 45 (s m^{-1}) and nothing was stated about the albedo (Howell and Evett, 2012). Medina et al. (1998) showed that irrigated olive trees and a vineyard, more comparable to cultivation in rows of the ‘Dutch U system’, had a median crop albedo which was almost the same as for grass (0.2). For alfalfa the constant values in the Penman-Monteith equation were respectively 1600 and 0.38 instead of the 900 and 0.34 for grass (Howell and Evett, 2012). In general estimated ET_0 will be 20% to 30% higher, if alfalfa instead of grass is used as reference crop (Allen and Pereira, 2009).

If K_C values exceed 1.4, the risk to overestimate ET_C is increased (Allen et al., 1998). Normally a K_C value larger than 1.4 does not occur in case of large areas of vegetation, but definitely may occur in case of a single row of trees, due to the oasis and clothesline effect (Allen et al., 1998). The clothesline effect is caused by the height of vegetation which is much greater than the height of the surrounding vegetation, thereby the aeration is increased (Allen et al., 1998). The oasis effect is caused by the higher water availability in the substrate than the water available for the surrounding vegetation and thereby the K_C value is increased, the oasis effect is presented in figure 2. Because the trees grown in the ‘Dutch U system’ were well watered, were grown in rows and were much higher than the field, the oasis and clothesline effect have occurred during cultivation. In a previous experiment in the ‘Dutch U system’, by the end of the growing season all tree species grown had a higher K_C per area of substrate than 1.4 (alfalfa was taken as reference crop) (some examples are shown in Appendix I, table 1).Very high K_C values (up to K_C=2.6) were observed in coffee crops grown in hedgerows as well (Pereira et al., 2011). Also the production of *Ligustrum Japonicum* in containers resulted in a maximum crop coefficient of 3 when ET_0 was based on the container area (Beeson, 2004). However, the maximum K_C value became 0.63 when ET_0 was expressed per area of coverage by the canopy (Beeson, 2004). “An upper limit of 2.5 is usually placed on K_C, - per unit of ground area-, to represent an upper limit on the stomatal capacity of the vegetation to supply water vapour to the air stream under the clothesline or oasis conditions” (Allen et al., 1998).

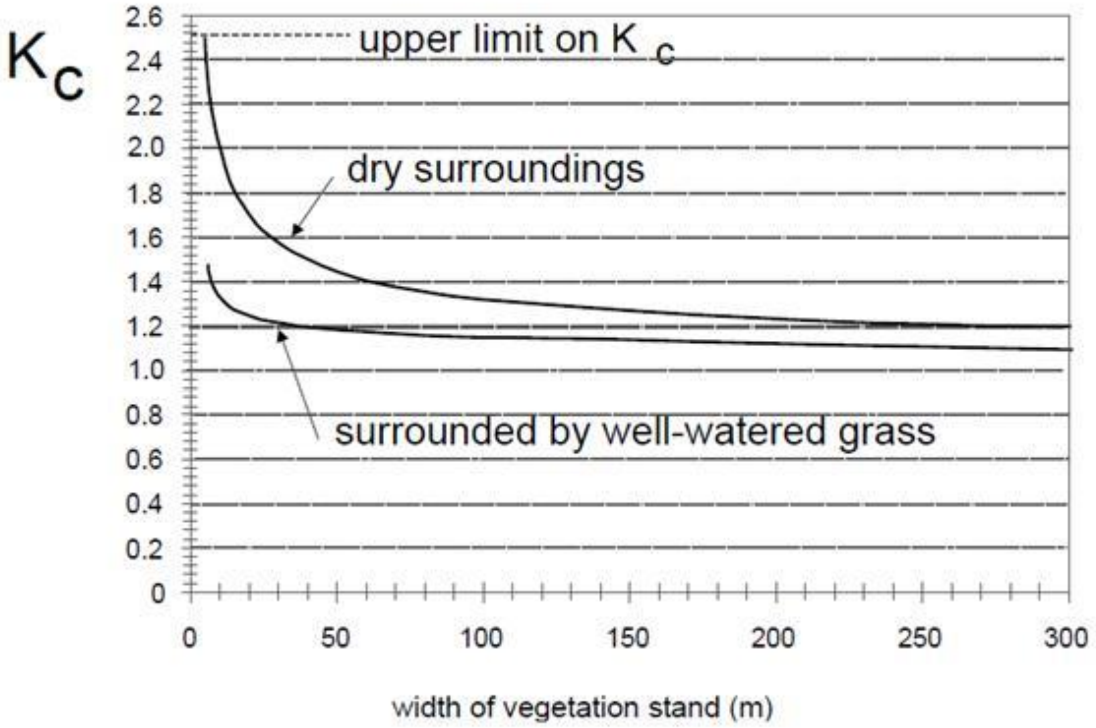

Fig. 2. K_C curves for small areas of vegetation under the oasis effect as a function of the width of the expanse of vegetation for conditions where RHmin = 30%, u2 = 2 m/s, vegetation height (h) = 2 m. (Allen et al., 1998 pp. 203)

In grapevines, grown in hedgerows, K_C value was highly correlated to LA and LAI (Williams and Ayars, 2005) (fig. 3A). Pereira et al. (2011) also found a high linear correlation between LAI and the K_C of a coffee crop grown in hedgerows (fig. 3B), and gave examples of similar results for distinctive crops. By assuming that the use of water per leaf area of the irrigated trees was equal to the use of water per leaf area of the grass reference crop (LAI = 2.88), K_C was described by the linear formula of 0.347*LAI (to determine LAI, LA was divided by total ground area) (Pereira et al., 2011). Such a linear correlation is only valid if $LAI \leq 3$, because if $LAI>3$ the canopy will be self-shaded and thereby the transpirative power of the canopy will be reduced (Pereira et al., 2011). However, the linear correlation of Pereira et al. (2011) was not valid in case of the results of different tree species grown in the ‘Dutch U system’ the previous year, since all the calculated linear parameters (K_C / LAI) were > 0.347 (Appendix I, table 2). Nevertheless, K_C will be tried to be correlated to LAI to be able to calculate ET_C during the growing season.

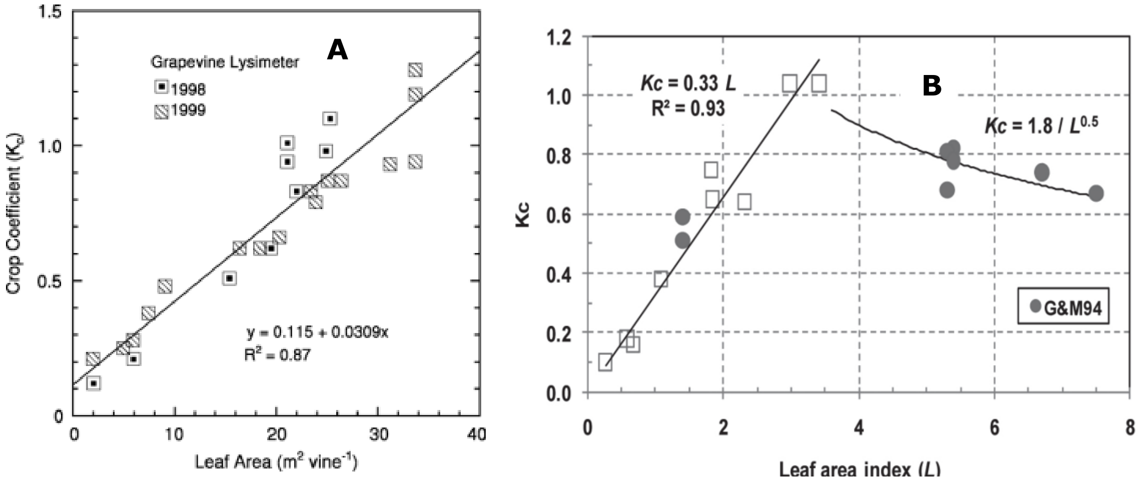

Fig.3. A. The relationship between the calculated crop coefficient (Kc) and the estimated leaf area per vine. Thompson Seedless grapevines were grown in lysimeters during 1998 and 1999. The soil surface area per vine was 7.55 m^{-2} (Williams and Ayars, 2005).
B. Crop coefficient of the coffee crop (K_C) as affected by leaf area index (L). Results from a different study were presented and were indicated by G&M94 (Pereira et al., 2011).

If ET_C is calculated by the combination of ET_0 and LAI, ET_C becomes independent of plant size and spacing (Pereira et al., 2011; Beeson, 2010). Due to a smaller plant distance, or by an increase in leaf area per unit of soil area (due to plant growth), ET_C would be increased. These changes do influence the LAI as well. For this reason crop coefficients correlated to LAI will take into account the influence on transpiration due to plant growth or spacing and thereby the model will become more independent of different plant- and growing conditions. The independency is important, because until now the determined K_C factors of different nursery crops grown in containers were only valid under the specific conditions (container size, plant size and distance) of determination (Derkx, 2011).

The percentage of interception of radiation (F_i) by a homogeneous canopy is described by an exponential extinction function of LAI (Pronk et al., 2003):

Equation 4: $F_i = 1 - e^{-k * LAI}$

Where
F_i = the percentage of PAR intercepted
k = the radiation extinction coefficient
LAI = the leaf area index

If the radiation extinction coefficient is known, LAI can be estimated by the outcome of measurements of interception of radiation.

Objectives For the project ‘Teelt de grond uit’, the water balance of the ‘Dutch U system’ was not fully closed in previous years. Therefore, the current research was performed. The first objective of the research was to close the water balance of the *Tilia* (*Tilia europaea ‘Pallida’ L*) trees grown in the ‘Dutch U system’. Especially the input of water by precipitation and the amount of water leaving the system by evapotranspiration are investigated. The second objective, and main goal of the research, was to develop a basic model of the water balance of the *Tilia* trees grown in ‘Dutch U system’. A basic model had to be developed in such a way that the model can be adapted easily to other tree species in future. Therefore K_C values were tried to be correlated to LAI, and K_C values from observations and simulations were compared.

2. Material and methods

The water balance of *Tilia* (*Tilia europaea 'Pallida'* L.) trees grown in the 'Dutch U system' was determined from April 23 until August 31. The 'Dutch U system' was located in Randwijk (the Netherlands), on the applied plant research centre of nursery stock. Besides *Tilia,* many other trees species were grown in the other rows of the 'Dutch U system'. The 'Dutch U system' consist of many rows with a length of 24 m. The rows were placed in pairs, top height of the rows was 70 cm above the ground. The distance between paired rows was 9 cm. The (grass) path distance between the different pairs of rows was 1.25 metres (fig. 4). The rows of the 'Dutch U system' were oriented north-south and were formed by a perforated plastic (airpot plastic) having a width of 59.5 cm. The (length) sides of the plastic were hanged in two separated iron rails, on a distance of 24 cm, in this way a half circle was formed. The iron mounting overlapped the substrate a little bit, resulting in an open space from iron to iron of 21 cm (showed in fig. 4). The rows of the 'Dutch U system' were filled with substrate, a mixture of peat. On top of the substrate a layer of wood chip was applied to reduce evaporation, and served as a kind of mulch. Controlled release fertilizer was applied. The *Tilia* trees were planted on a mutual distance of 20 cm on April 23, 2012. Drip-irrigation was used to apply irrigation and pest and disease control was applied if necessary. However, on August 16 a 100% infestation of gall midge was observed. An experienced entomologist assumed it to be already the second infestation of the season. After this was found out, the *Tilia* trees were sprayed preventively. On the 20th of June the trees were pruned and bound to the trellis.

Before planting the water content at pF =1, pF = 1.7 and wilting point of the substrate were determined by Blgg Agroexpertus. Volumetric water content of the substrate at pF = 1 was 69 Vol. % (pF = 1), at pF = 1.7 the volumetric water content was 44 Vol. %. Thus, 25 Vol. % of the substrate could be EAW, corresponding to an amount of EAW of 45 L of water m^2 of substrate (calculation shown in Appendix V). The water content of the substrate before planting was calculated using the results of the substrate analysis performed by Blgg Agroexpertus. The substrate contained 41 Vol. % of water before planting (results of analysis and calculations are shown in Appendix V). The water content at pF =1 was determined again during the experiment on July 20 early in the morning. The substrate had drained on July 19. Therefore the substrate was assumed to be at pF = 1 when it was sampled. Three samples of 180 cm^3 were taken at the top layer of the substrate. Weight before and after drying was measured, and the results were used to determine Vol. % of water in the substrate at pF = 1.

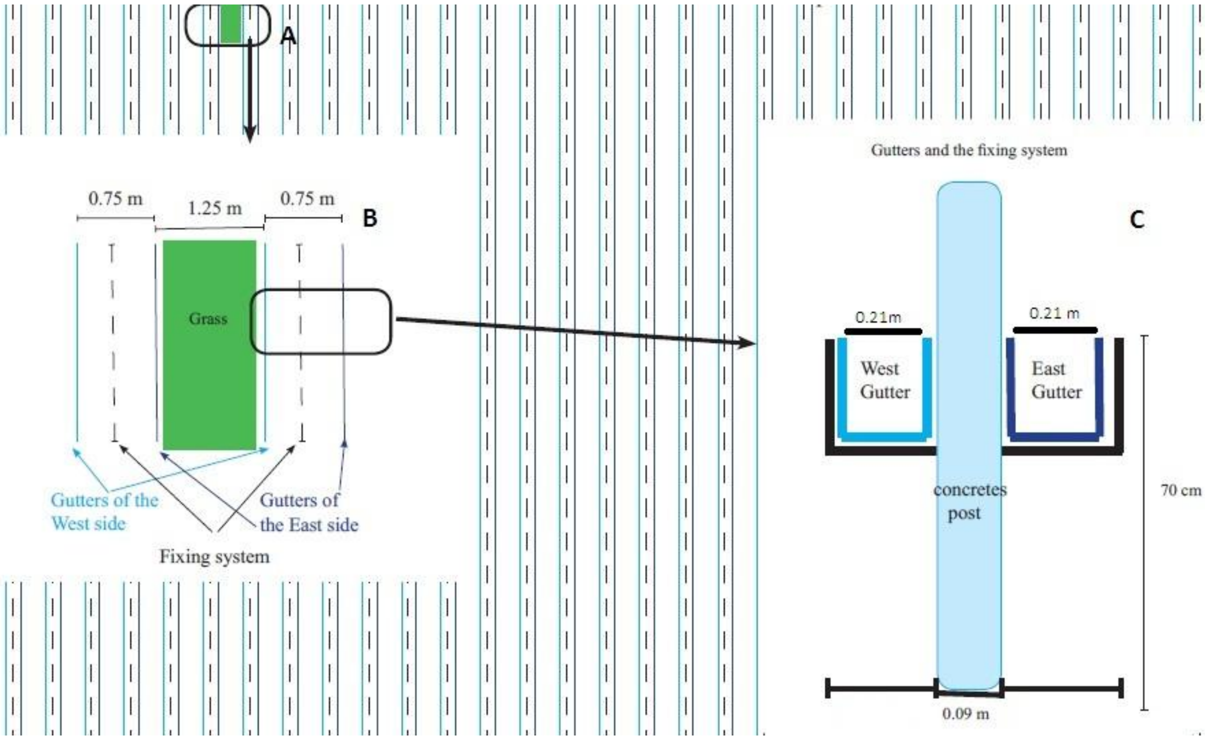

Fig. 4. **A**. Top view of the 'Dutch U system'. **B**. Detailed top view of the 'Dutch U system', (grass) path (green) with on both sides a pair of rows (between blue lines). **C**. A front view of paired rows, in the middle the concrete post is shown, holding a row on both sides.

2.1 Measuring the water balance

To determine the water balance of the system, water input into the substrate and water output from the substrate was determined. All flows were expressed in litres of water per area of substrate (L of water $m^{-2}$of substrate) .

The amount of water applied by irrigation was registered. Data about gross precipitation was obtained from the KNMI precipitation station Zetten, located on the research centre and was measured every morning at 10:00. The amount of precipitation reaching the substrate, the net precipitation (throughfall + stemflow), was determined. Therefore, ten precipitation collectors were made and placed randomly in the west row. Sides of plastic pots were used to form an open circle with a diameter of 21 cm, and these were placed around a *Tilia* tree. In this way the precipitation collectors had exactly the same width as the open space between the two iron mountings holding the plastic airpot. A small hole was made in the bottom a plastic bag. The *Tilia* trees were put through the small hole of the plastic bag. The side of the plastic bag was fold over the side of the plastic pot and the hole was bound water tight around the stem by elastic. In this way the precipitation collectors were formed. Two additional rain collectors were placed in the open field and served as reference to measure gross precipitation (in this way it was possible to determine the input of precipitation on a different time interval than the interval of the KNMI precipitation station Zetten). The amount of water in the precipitation collectors was divided by the area of the rain collectors. In order to calculate the percentage of precipitation going into the substrate, this number was divided by the reference precipitation. When the period of precipitation collection took more than two days (happened three times, due to the impossibility to empty the precipitation collector), the measurement was not processed as a result. These results were not used, because the evaporation of water from the precipitation collector influenced the results. Because the mounting of the system overlapped the substrate, while the flows of water were expressed per area of substrate, net precipitation was multiplied by the ratio of 21/24 cm.

All the drainage water was collected by a drainage collector (pipe) below the airpot and by this pipe the drainage water ended up in a closed storage tank. The amount of drainage water was measured automatically before it entered the storage tanks, from June 26 onwards. On June 26 the drainage meter was also calibrated. Before this period the drainage meter did not work properly. Therefore, the amount of drainage water was determined manually for the period from April 23 till June 25.

It was proposed to determine evapotranspiration of the *Tilia* trees with help of mini-lysimeters. Therefore, five trees were grown in a little row (comparable to the 'U Dutch system') of 1.2 m length, and by weighing the little rows it was proposed to measure evapotranspiration. The *Tilia* trees were transplanted into the little rows on June 1. Due to the late transplanting the trees were behind in growth compared to the large rows of the 'U Dutch system'. By the end of July the trees in the little rows were grown too less, and some even did not grow. For this reason it was unfortunately decided to stop measuring evapotranspiration with help of the little rows. Instead, evapotranspiration was determined based on the different flows of water into and out from the substrate in combination with equation 1.

The water balance is presented for three consecutive periods, the first period is from transplanting (April 23) till June 30, the second period is the month of July and the third period is the month of August. Per period the change in the amount of water in the substrate was determined. To determine the amount of water in the substrate by the end of the period, all inputs of water into -and outputs of water from the substrate were summed after the last drainage event of that period. During the day a drainage event occurred, the substrate was assumed to be at pF = 1 and thereby the amount of water retained by the substrate was known, consequently. The output of water was subtracted from the input of water and the calculated difference was subtracted from the amount of water retained at pF =1. In this way the actual amount of water in the substrate was determined.

2.2 Penman-Monteith

Reference crop evapotranspiration (ET_O) was calculated by making use of the FAO Penman-Monteith equation (eq. 2). The formulas to calculate the slope of the vapour pressure curve and the psychometric constant (0.067 kPa °C) were obtained from the article of Nandagiri and Kovoor (2005), the formulas are included in Appendix III. Weather data were obtained from the nearby university weather station, meteostation- de Veenkampen, located in Wageningen. In this station temperature was measured 1.5 m above soil, while in the FAO Penman-Monteith equation the temperature at a height of two meters above soil was needed as temperature input. Nevertheless, the temperature data of meteostation-Haarweg was used as temperature input. Because of the frequency of irrigation, ET_0 was calculated on an hourly basis. ET_O was calculated for alfalfa, since it was referred as tall reference crop. To compute ET_0 on an hourly basis the constant of 1600 was divided by 24.

In case of the little rows, it was proposed to determine K_C on a two week interval, because ET_0 calculations using the FAO P-M equation were calibrated for ten-day or monthly intervals (Allen et al., 1998). As the little rows were no longer available, ET_C was determined using the water balance of the large rows. To do so, the amount of water in the substrate at the start of the measuring period need to be equal to the amount of water in the substrate by the end of the period, to exclude that differences in the amount of water in the substrate are attributed to evapotranspiration by the crop. Therefore the ET_C was determined between two drainage events, because the amount of water in the substrate was assumed to be equal on both dates (pF = 1). Because ET_C was determined between two drainage events, the intervals of K_C determination were not equal. Time intervals of at least 7 days were taken. K_C was determined for July 13 and 23, and for the 4th, 14th and 25th of August. These dates were the middle of the measuring period. For the day where the drainage event occurred, the amount of water applied by irrigation and the estimated amount of precipitation going into the substrate were summed. For the same day, evapotranspiration was estimated (estimated by multiplying ET_0 times the K_C value determined by the previous measurement). Estimated evapotranspiration and measured drainage were subtracted from the input of water by irrigation and precipitation. The difference was assumed to be equal to the difference in the amount of water in the substrate for that period. Then all flows of water were known and equation 1 was used to determine total ET_C during the period between the two drainage events. To define the K_C value for the *Tilia* trees, ET_C was divided by ET_O (both expressed per area of substrate). ET_C was assumed to be non-water limited, since irrigation was applied several times a day. It was proposed to check this assumption, by weighing the little rows on a sunny and warm day every half an hour. Because the trees in the little rows were much smaller than the other trees, these measurements were not performed. The measurements would not have been representative, since the need of water would have been much lower for these small trees.

2.3 Plant measurements

Plant development was followed over the season. For this reason ten randomly chosen plants were measured on a 3 week interval. Of every tree the height, the maximum width perpendicular to the row and the maximum width parallel to the row was measured. Initially it was proposed to measure the width at different heights, but because the width at different height of trees was quite uniform, these measurements were not performed.

The interception of PAR was measured approximately every two weeks. The interception of PAR was measured for the first time on June 12. The SunScan Canopy Analysis system, type SS1, from Delta-T Devices Ltd was used to measure the interception of PAR. A probe with a length of 1 m was used to measure the level of PAR below the trees. In a non-shaded space next to the 'Dutch U system', the beam fraction sensor was placed to monitor the incident level of PAR, which was used as reference. The measurements were performed around solar noon (13.00). Because of the construction of the 'Dutch U system' and the influence of other measurements (destructive harvest, rain interceptors), the interception of PAR was always measured using the trees grown in the eastern row, on the east side of the trees. The level of

PAR below the canopy was measured at least 30 times. The level of PAR below the canopy was measured in two ways, parallel and perpendicular to the row. If the interception of PAR was measured parallel to the row, the probe was hold near the stem. When the interception of PAR was measured perpendicular to the row, 40 cm of the probe was shaded by aluminium foil. During the measurements performed perpendicular to the row, the interception of PAR of one pair of rows was measured. Perpendicular measurements were not performed at places next to the interceptors of rain, next to places of destructive harvest and places next to the concrete posts of the 'Dutch U system'. The measurements were always performed at the level of the mounting of the system (so the mounting did not influence the measurements). Before each session of light measurements, the level of PAR in the open space was measured with the probe around ten times. This was done for two reasons. First, to check if the results of measurements performed under the same conditions (measurements performed in the open field next to the 'Dutch U system') did not differ too much between the two devices (a difference up to 10% was considered to be acceptable). And secondly, to calibrate the real measurements, because a correction factor for the systematic difference between the two devices was determined using these measurements. To calculate the percentage of interception of PAR, the level of PAR below the *Tilia* canopy was divided by the reference level of PAR (which was multiplied by the correction factor), and this number was subtracted from 1.

Leaf area (LA), leaf area index (LAI) and fresh- and dry weight of the leaves of the *Tilia* trees were determined on June 26, July 20 and the 17th of August. On these dates three randomly chosen trees were harvested destructively. On the same days, the interception of PAR was measured. Per destructively harvested tree, LA was divided by the corresponding leaf weight to determine specific leaf area (SLA). Of the three trees harvested, average SLA was determined per date. Before cutting, the height and the maximum width, perpendicular and parallel to the row, of the trees were measured. Directly after the destructive harvest, LA per tree was determined with help of a leaf area meter (LI-COR 3000). LAI was calculated; LA was divided by the area of planting distance times the width of the substrate. Because the trees did grow hardly over the edge of the mounting of the system, the width of the substrate was taken as reference.

The results of the determination of LAI and corresponding measurements of PAR interception were used to calculate the radiation extinction coefficient, using equation 4. The radiation extinction coefficient and the results of the interception of PAR were used to estimate the LAI on the particular days of measuring the interception of PAR. In this way the LAI development was determined over time.

2.4 Development of the model

A model simulating the water balance of *Tilia* trees grown in the substrate filled 'Dutch U system' was developed. It is a deterministic model, written in FST: FORTRAN Simulation Translator. The model represents the specific conditions of the 'Dutch U system' as described earlier in the material and methods. Because irrigation events occurred several times a day, the dynamic processes are simulated on an hourly time interval. Weather data required to run the model are net radiation, daily total radiation, soil heat flux (all W m^{-2} and in the model converted into MJ m^{-2} h^{-1}), air temperature at a height of 1.5 m (˚C), relative humidity (%), wind speed (m s^{-1}) and precipitation (mm). On August 16 a gall midge infestation was found and all the trees were affected. It is not known how the infestation have influenced the results, and thereby the developed model as well. An overview of the model can be found in appendix II.

The model was developed for the period of July 1 until August 31 of the year 2012. The data of this period was used to develop the model. Irrigation and precipitation were given as input data for the model. The LINTUL-2 model (described by van Ooijen and Leffelaar (2008)) was used as starting point of the development of the current model. A module to predict evapotranspiration was made. ET_0 was calculated (FAO P-M equation) and K_C was correlated to the development of LAI. The development of LAI was based on the interception of PAR and the LUE and SLA defined before.

LAI was estimated for different moments in time using the results of the measurement of interception of PAR and the light extinction coefficient. The interception of PAR was measured perpendicular- and parallel to the row of trees. Based on these measurements, LAI was estimated and compared to the LAI determined by the destructive harvest. The results of the interception of PAR measured perpendicular to the rows predicted LAI the best in relation to the determined LAI (see results and discussion). Therefore the data of these measurements were used to continue model development. The percentage of interception of PAR was plotted against time, and a trend line was fitted. Based on the equation of the trend line, the daily interception of PAR was calculated. To know the amount of incoming PAR, DTR was multiplied by a half. Then the fraction of PAR interception was multiplied by PAR, to calculate the intercepted amount of PAR. The daily interception of PAR was summed for the period from June 26 until September 4. The LAI on June 26 and September 4 was estimated with help of the average K_C value and predicted interception of PAR (was based on the formula of the trend line). The estimated LAI of June 26 was subtracted from the estimated LAI of September 4. In this way the increase in LAI was known for this period. The increase in weight of the leaves was calculated, therefore the increase in LAI was divided by SLA. To determine the LUE of the *Tilia* trees, the increase in dry matter of leaves was divided by the total amount of intercepted PAR (for the calculation see appendix V).

K_C was determined for 5 different moments in time during the period of July 1 until August 31. Corresponding LAI was calculated for these dates. To calculate LAI, the interception of PAR was multiplied by SLA and LUE. In this way LAI was integrated over time, so the LAI of every day was known. The integration of LAI started on June 26, with a starting LAI of 0.87 (based on the measurements of interception of PAR). Finally K_C was linearly correlated to LAI.

2.5 Description of the model

Conversions of input variables Net radiation, soil heat flux and daily total radiation are input variables of the model and are expressed as W m^{-2} of substrate. The calculations in the model are based on these variables expressed as MJ m^{-2} of substrate h^{-1}. Therefore these variables are converted. The input variables are multiplied by 0.0036. Daily total radiation is multiplied by 0.5, to estimate the total amount of photosynthetic active radiation (PAR). Relative humidity was given as input variable. Saturation vapour pressure (e_s) is calculated by the formula of Nandagiri and Kovoor (2005): $ES = 0.6108 * e^{((17.27*T)/(T+237.3))}$ [kPa]. To calculate actual vapour pressure (e_a), e_s is multiplied by relative humidity divided by 100. The slope of the vapour pressure curve (Δ) is calculated using the formula of Nandagiri and Kovoor (2005): $SVP = (4098 * 0.6108e^{((17.27 * T)/(T + 237.3))}) / (T + 237.3)^2$ [kPa $^{\circ}C^{-1}$].

Water balance The hourly change in the amount of water in the substrate is described in the model by (L of water m^{-2} of substrate h^{-1}): RWA = RAININ + IRRIG – ETA – DRAIN. RWA is the hourly change in the amount of water in the substrate (WA). RAININ and IRRIG represent the hourly amount of water going into the substrate by precipitation and irrigation, respectively. ETA is the loss of water from the substrate by evapotranspiration per hour, and DRAIN is the hourly loss of water from the substrate by drainage.

The characteristics of the substrate WCFC (water content at pF = 1), WCpF17 (water content at pF = 1.7) (-) and the volume of substrate per area of substrate GVOL (L of substrate m^{-2} of substrate) are given under initial conditions. In case of the current experiment the values of WCFC, WCpF17 and GVOL were respectively 0.69, 0.44 and 180.

Precipitation The fraction of precipitation going into the substrate is assumed to be constant during the period of growing. In case of the *Tilia* trees grown in the 'Dutch U system' during the current experiment, the average percentage of gross precipitation entering the substrate was 0.93. The hourly input of precipitation into the substrate is described in the model by: RAININ = PREC * FRRAIN (L of water m^{-2} of substrate h^{-1}). PREC is the amount of precipitation per hour (mm h^{-1}) and FRRAIN is the percentage of gross precipitation entering the substrate. The daily precipitation data of meteostation Zetten was converted into hourly precipitation data, based on the hourly distribution of precipitation measured in meteostation de Veenkampen.

Irrigation Irrigation data was given as input variable for the model. In this way it was possible to compare the simulated- and determined evapotranspiration and drainage. However, in future the model might be used to automate the application of irrigation. Then the moments of irrigation can be based on an allowable container water deficit concept as applied in the CCROP model of Million et al. (2011). Beeson (2006) recommended for different nursery stocks to start irrigation if the deficit in EAW was 20 to 40%. In case of the current model 30% was taken as threshold. Thus, if the water content of the substrate (WC) will be lower than WCFC–((WCFC–WCpF17)*0.3), irrigation will be started (IRRIG). To prevent the water content of the substrate to reach pF = 1 due to irrigation, IRRIG will be only 0.10*(WCFC-WCpF17)*GVOL (L of water m^{-2} of substrate h^{-1}). Beeson (2010) and Million et al. (2011) did not include a module to prevent salinization in their model, and drainage still occurred even irrigation was automated by the current model. Therefore, no module to prevent salinization was included in the current model.

Drain If the amount of water in the substrate exceeds the amount of water that can be retained by the substrate at pF = 1, drainage will occur (L of water m^{-2} of substrate h^{-1}). If this is not the case, drainage will be 0: DRAIN = INSW(WCFC * GVOL – WA), WA – WCFC*GVOL, 0), where WA is the actual amount of water in the substrate.

Evapotranspiration Evapotranspiration (ETC) of the *Tilia* trees is calculated with help of equation 2 and 3. The equation is adapted to the alfalfa reference crop. Thus water lost from the substrate by evapotranspiration is calculated in the model by: ETA = ET0 * KC * ETRED. Where ETA is the amount of water lost from the substrate by evapotranspiration (L m^{-2} of substrate h^{-1}) and ET0 is the reference evapotranspiration of alfalfa (L of water m^{-2} of substrate h^{-1}). If ET0 is calculated to be lower than 0 (due to condensation of water vapour on the leaf), ET0 is set to be 0, because condensation is no input of water into the substrate. In this way ETA cannot be a negative value. When available water becomes limiting, ETA is reduced by the evapotranspiration reduction factor ETRED. Because ET_C of the *Tilia* trees was assumed to be determined under non-water limiting conditions, the effect of water limitation on ET_C of the *Tilia* trees was unknown. In the CCROP model of Million et al. (2010) evapotranspiration was assumed to be reduced significantly when the actual amount of EAW was 50% of the potential amount of EAW. In case of the current model the same assumption was made. In case of the used substrate EAW was between a water content of 0.69 and 0.44, 50% EAW was reached at a water content of 0.565. ETRED is 1 when WC is between 0.565 and 0.8, ETRED is decreasing linearly from 1 to 0 between a WC of 0.565 and 0.44 and when the WC is below 0.44, ETA is assumed to be 0. Because drainage can occur, no reduction of evapotranspiration due to a WC above pF = 1.7 is assumed.

K_C was linearly correlated to LAI (see results and discussion), and the correlation is applied in the model. K_C = 0.90 * LAI – 0.45 (-). LAI is predicted by the model as well. Based on the LAI of the previous hour, the interception of PAR of the actual hour is calculated: PARINT = PAR * (1. – EXP(–K * LAI)) (MJ m^{-2} of substrate h^{-1}). PAR is the hourly incoming photosynthetic active radiation (MJ m^{-2} of substrate h^{-1}). K is the extinction coefficient of light, in case of the current experiment K has a value of 0.50. Based on the intercepted PAR, the hourly increase of leaf weight is determined: GLEAF = LUE * PARINT (g of leaf m^{-2} of substrate h^{-1}). LUE is the light use efficiency of the trees (only production of leaf), in case of the current experiment LUE is set to 0.46 g of leaf production MJ^{-1} of PAR intercepted (see results and discussion). Based on the increase of leaf weight, the increase in LAI is determined: RLAI = GLEAF * SLA (m^2 of leaves m^{-2} of substrate h^{-1}). SLA is the specific leaf area, in case of the current research SLA is $1.35*10^{-2}$ (m^2 of leaves g^{-1} of leaves). RLAI is integrated over time to calculate actual LAI: LAI = INTGRL(LAII, RLAI) (m^2 of leaves m^{-2} of substrate). LAII is the initial LAI at the moment of starting the simulation. In case of the current research, LAII is 0.99 (m^2 of leaves m^{-2} of substrate).

2.6 Overview of the model

In this section the formulas of the model are given, including a short description of the formulas and used assumptions.

Under Initial the initial conditions of LAI and the amount of water in the substrate are given.

LAII	= 0.99 [m^2 of leaf m^{-2} of substrate]	Initial leaf area index

WAI = 0.63 *GVOL [L of water m^{-2} of substrate] Initial amount of water substrate
GVOL = 180 [L m^{-2} of substrate] The volume of a row of the 'Dutch U system'

The parameters of the used substrate are:

WCFC = 0.69 [-] Vol. percentage of water in the substrate at pF = 1
WCpF17 = 0.44 [-] Vol. percentage of water in the substrate at pF = 1.7

In case of substrate, drainage occurs at pF = 1 and wilting point is reached at pF = 2. The amount of water hold by the substrate between pF = 1 and pF = 1.7, was assumed to be easy available water (EAW). The Vol. percentage of water in the substrate at pF = 1 and pF = 1.7 were assumed not to change during the season.

The "MEASUREMENTS" and "MEASURED" statements are used to call the needed weather data in the model. The weather data called by the "MEASURED" statement are:

water	[L of water m^{-2} of substrate h^{-1}]	Irrigation
dtrad	[W m^{-2}]	Daily total radiation
netradiation	[W m^{-2}]	Net radiation
temp	[˚C]	Temperature
sohe	[W m^{-2}]	Soil heat flux
relhum	[%]	Relative humidity
wind	[m s^{-1}]	Wind speed
prec	[L of water m^{-2} of substrate h^{-1}]	Precipitation

Under "Run control" the conditions to execute the model are given. The time step of the model is an hour. In the current model the simulation starts on July 1 (StartDOY = 183, because 2012 is a leap year).

The second part of the model starts with the "DYNAMIC" statement. In this part the dynamic calculations are made. In the current model this part starts with the conversion of the weather data and clarification of the parameters of the crop. The converted weather data are:

NRDD = netradiation / 1*10^6 * 3600 [W m^{-2} * s h^{-1} = MJ m^{-2} h^{-1}]
Net radiation
SHF = sohe / 1*10^6 * 3600 [W m^{-2} * s h^{-1} = MJ m^{-2} h^{-1}]
Soil heat flux
PAR = 0.5 * dtrad / 1*10^6 * 3600 [W m^{-2} * s h^{-1} = MJ m^{-2} h^{-1}]
Photosynthetic active radiation

PAR was assumed to be half of the daily total radiation.

Parameters of the *Tilia* trees are:

LUE = 0.46 [g of leaf biomass MJ^{-1} of PAR intercepted] Light use efficiency
SLA = 134.8 [cm^2 of leaf g^{-1} of leaf] Specific leaf area
K = 0.50 [-] Light extinction coefficient

FRRAIN = 0.93 [-] Percentage of precipitation entering the substrate

The percentage of precipitation entering the substrate was assumed to be equal over the season, as well to be independent of the characteristics of a rainfall event. Therefore the input of precipitation into the substrate was a forcing function.

Increase of leaf area index (LAI) is determined by the interception of PAR. SLA and LUE are used to convert the interception of PAR into the increase of LAI. Equation 4 is used to calculate the interception of PAR. The hourly increase of LAI is integrated over time. Because between the paired rows of the 'Dutch U system' were wide paths, the increase of LAI was assumed to be not limited by the shading of the canopy.

PARINT = PAR * (1 – e $^{(-K * LAI)}$) [MJ m^{-2} h^{-1} * (-) = MJ of PAR m^{-2} of substrate h^{-1}]
Interception of PAR
GLEAF = LUE * PARINT [g MJ^{-1} * MJ m^{-2} h^{-1} = g of leaf m^{-2} of substrate h^{-1}]
Increase of leaf weight
RLAI = GLEAF * (SLA / 10000) [g m^{-2} h^{-1} * m^{2} g^{-1} = m^{2} of leaf m^{-2} of substrate h^{-1}]
Increase in LAI
LAI = INTGRL (LAII, RLAI) [m^{2} of leaf m^{-2} of substrate]
Leaf area index

Evapotranspiration is calculated. To calculate evapotranspiration, the slope of the vapour pressure curve (SVP) and saturation vapour (ES) pressure have to be calculated first. The saturation vapour pressure and the slope of the vapour pressure curve are calculated by using the equations of Nandagiri and Kovoor (2005) (appendix III).

ES = 0.6108e$^{(17.27 * temp) / (temp + 237.3)}$ [kPa]
Saturation pressure of water vapour
EA = relhum / 100 * ES [kPa]
Actual pressure of water vapour
SVP = (4098 * 0.6108e$^{(17.27 * temp) / (temp + 237.3)}$ / (temp + 237.3)^{2} [kPa ˚C^{-1}]
Slope of the vapour pressure curve

Evapotranspiration is calculated using equation 2 and equation 3. Equation 2 is adjusted to alfalfa. K$_{C}$ is correlated to LAI, in order to estimate K$_{C}$ over the season. During night, condensation of water vapour on the leaf can occur and ET0 will have a negative value. Because condensation is assumed to be no input of water into the substrate, negative values of reference evapotranspiration are set to be 0. ET0NEG is calculated firstly and with help of a function negative values of ET0NEG are changed into 0 to determine ET0. To calculate actual evapotranspiration (ETA), crop reference evapotranspiration (ET0) of alfalfa is multiplied by the crop coefficient (KC). ETA is integrated over time to calculate TETA.

KC = 0.90 * LAI – 0.45 [-]
Crop coefficient
ET0NEG $= \frac{0.408 * \mathrm{SVP} * (\mathrm{NRDD} - \mathrm{SHF}) + 0.067 * ((1600 / 24) / (\mathrm{temp} + 273)) * \mathrm{wind} * (\mathrm{ES} - \mathrm{EA})}{\mathrm{SVP} + 0.067 * (1 + 0.38 * \mathrm{wind})}$

$$\left[\frac{\frac{\mathrm{kg}}{\mathrm{MJ}} * \frac{\mathrm{kPa}}{^{\circ}\mathrm{C}} * \frac{\mathrm{Mj}}{\mathrm{m} * \mathrm{m} * \mathrm{h}} + \frac{\mathrm{mm}}{^{\circ}\mathrm{C} * \mathrm{h}} * \mathrm{kPa}}{\frac{\mathrm{kPa}}{^{\circ}\mathrm{C}}} = \text{L of water m}^{-2}\text{ of substrate h}^{-1}\right]$$

Reference evapotranspiration

ET0 = INSW (ET0NEG, 0, ET0NEG) [L of water m^{-2} of substrate h^{-1}]
Reference evapotranspiration, negative values of reference evapotranspiration are excluded

ETA = ET0 * KC * ETRED [L of water m^{-2} of substrate h^{-1}]
Actual evapotranspiration

TETA = INTGRL(ZERO , ETA) [L of water m^{-2} of substrate]
Total evapotranspiration

ETRED is a reduction factor of actual evapotranspiration. When the actual water content of the substrate becomes below half of EAW, actual evapotranspiration will be reduced. The reduction factor is increasing linearly from 0 to 100% reduction, when the water content of the substrate is decreasing from 50% of EAW to WCpF17. No reduction of evapotranspiration due to a WC above WCFC (pF = 1) and a WC between WCFC and 50% EAW is assumed. Intercepted precipitation by the leaves is assumed to have no negative influence on the evapotranspiration.

Irrigation is given as input variable. Therefore the simulated irrigation is exactly equal (amount and interval of application) to the irrigation applied during the current research. For this reason, IRRIGA is equal to “water” [L of water m^{-2} of substrate h^{-1}], whereby “water” is equal to the irrigation applied in the performed experiment. Also an equation was developed to automate the application of irrigation. Then irrigation will be applied if the actual water content of the substrate is decreased below 70% of the EAW. Per application of irrigation, 10% of the EAW will applied. Only one of the two options of irrigation application can be switched on during a model run. A fixed percentage of precipitation is entering the substrate. During the current experiment the average percentage of precipitation entering the substrate was determined (see results) and this number is applied in the current model as forcing function to calculate the input of precipitation. Therefore the percentage of precipitation entering the substrate is assumed to be constant over the season and is assumed to be independent of characteristics of the rainfall event. The hourly input of precipitation and precipitation are both integrated over time.

IRRIGA = water [L of water m^{-2} of substrate h^{-1}]
IRRIGA = INSW (WC – (WCFC – (WCFC – WCpF17) * 0.3), 0.10 * (WCFC – WCpF17) * GVOL , 0) [L of water m^{-2} of substrate h^{-1}]
Irrigation

TIRRIG = INTGRL (ZERO, IRRIGA) [L of water m^{-2} of substrate]
Total irrigation

RAININ = prec * FRRAIN [L of water m^{-2} of substrate h^{-1}]
Input of precipitation

TRAININ = INTGRL (ZERO, RAININ) [L of water m^{-2} of substrate]
Total precipitation input

Drainage is assumed to occur if the actual amount of water in the substrate is larger than the amount of water that can be retained by the substrate at pF = 1. If the actual amount of water in the substrate is smaller than the amount of water that can be retained by the substrate at pF = 1, drainage will not occur. To calculate the hourly change in the amount of water in the substrate, the total output of water (drain and evapotranspiration) from the substrate is subtracted from the input of water (irrigation and precipitation) into the substrate.

DRAIN = INSW (WCFC * GVOL – WA), WA – WCFC * GVOL, 0)
[L of water m^{-2} of substrate h^{-1}]
Drainage
TDRAIN = INTGRL (ZERO, DRAIN) [L of water m^{-2} of substrate]
Total drainage
RWA = RAININ + IRRIGA – ETA – DRAIN [L of water m^{-2} of substrate h^{-1}]
Change in the amount of water in the substrate
WA = INTGRL (ZERO, RWA) [L of water m^{-2} of substrate]
Amount of water in the substrate
WC = WA / GVOL [-]
Water content of the substrate

Explanation of the used FST functions is given in Appendix IV.

2.7 Model testing

The developed model was tested. Therefore the simulated water balance was compared to the determined water balance for the period of July 1 until August 31 (measured: irrigation and drainage, determined: precipitation and evapotranspiration) An analysis of sensitivity of the model was performed. Therefore the different input variables and parameters of the *Tilia* trees, were in- and decreased by 10%. The relative effect of these changes on simulated ET_C was evaluated. Also a model run using the weather data of 2011 was performed, the initial parameters of the current research were used. Weather data, including precipitation data, were obtained from the nearby university weather station meteostation- de Veenkampen, located in Wageningen.

3. Results

The fraction of net precipitation (throughfall + stemflow) into the substrate ranged between 0.52 and 1.63 (table 1). The average fraction of net precipitation into the substrate was 1.06. These percentages of net precipitation were expressed, per open area between the mounting of the system, having a width of 0.21 m. The water balance is expressed per area of substrate (having a width of 0.24 m), so the area of substrate covered by the mounting is included. Therefore, the fraction of net precipitation was converted to the area of substrate. The fraction of net precipitation was multiplied by the factor 0.875 (0.21/0.24). For the different rainfall events the fraction of net precipitation expressed per area of substrate ranged between 0.46 and 1.43 mm (table 1). The average fraction of net precipitation, expressed per area of substrate (0.24 m), was 0.93., Just as Shachonovich et al. (2008) concluded, the average net precipitation was very heterogeneous.

Table 1. Percentage of net precipitation calculated for the open area between the mounting of the system and area of substrate, net precipitation was divided by the gross precipitation. Net precipitation was the average of 10 rain interceptors, standard deviations are shown between brackets.

Date (-)	Gross precipitation (mm)	Net precipitation (mm)	Fraction of net precipitation open area between mounting (width 0.21 m) (-)	Fraction of net precipitation per area of substrate (width 0.24 m) (-)
July 10	2.3	1.2 (0.39)	0.52	0.46
July 11	4.0	3.4 (0.56)	0.84	0.74
July 12	5.7	4.3 (2.00)	0.75	0.66
July 17	24.5	30.3 (6.70)	1.24	1.08
July 19	12.9	17.1 (4.84)	1.32	1.16
July 20	4.3	5.6 (1.19)	1.32	1.15
August 7	1.0	0.9 (0.22)	0.86	0.75
August 14	1.8	1.6 (0.88)	0.88	0.77
August 27	17.7	24.0 (8.11)	1.35	1.18
August 31	8.4	13.7 (4.24)	1.63	1.43

The fraction of net precipitation was unexpectedly high (larger than 1 if it was expressed per area of non-covered substrate). Unexpectedly, since a fraction of precipitation was expected to be intercepted by the canopy of the trees and a fraction of throughfall was expected to fall next to the substrate, resulting in a fraction of net precipitation smaller than 1. The fraction of net precipitation in the current research was much higher than the fraction of net precipitation (0.78) observed in vine trees grown in rows (Brecciaroli et al., 2012) and free stand olive trees (average fractions up to 0.75) (Gómez et al., 2002). On the other hand, in case of ornamentals grown in containers, fractions of net precipitation (sprinkler irrigation) larger 1 than were observed as well (Beeson jr. and Yaeger, 2003). And Gómez et al. (2002) showed that the fraction of throughfall differed among different points under one tree, whereby the fraction of throughfall reached 1.4 at certain points. Especially on the part of the tree the direction of wind was coming from, the fractions of precipitation throughfall were larger than 1. Thus the average fraction of 1.06 (expressed per area of non-covered substrate), was probably caused by the block effect of the *Tilia* trees. Thus, the wind in combination with the high trees and the wide paths in between the paired rows, had probably caused the high fraction of input of water by precipitation. The wind had probably influenced the results of the determined water balance as well, since the rain collectors were placed on the west row (during rainfall events the wind is mostly coming from the west). Due to the high and elevated trees in combination with the wind from the west, the rain was blocked by the trees, thereby the input of precipitation was higher in the west row than the east row. A suggestion made, because in case of other tree species grown in the 'Dutch U system', a lower drainage was observed in the east row compared to the west row. Of the determined water balance of the current research, drainage was measured on the east row, while the input of precipitation was determined on the west row. Therefore, the water balance and subsequent calculations were assumed to be influenced by the effect of the wind.

Because the trees acted like a wind and rain block, during the season an increase in fraction of net precipitation was expected due to the growth of the trees. But the results did not really show an increase in the fraction of net precipitation over the season. It looked like the depth (amount of precipitation) of the rainfall event was more of important than plant development. Although on July 20, the fraction of net precipitation was quite high (1.32) compared to the relative small depth of the rainfall event (4.3 mm). But in general, the fraction of net precipitation tended to be higher by deeper rainfall events, results which were in agreement with the results of Gómez et al. (2002).

Further research needs to be done to be able to determine the fraction of net precipitation in the model, based on characteristics of the rainfall event. It was not possible to determine the fraction of net precipitation, based on characteristics of the rainfall event. The amount of data was insufficient and the time step of the measurements was not in line with the time step of the model. To set clear hourly boundaries, the daily rain data have to be converted into hourly rain data. But the conversion was not possible to be made, since the distribution of the precipitation over the day was unknown. Boundaries could be set on e.g. the depth and intensity of the rainfall event and the effect of the wind. Because it was impossible to determine a specific fraction of net precipitation based on characteristics of the rainfall event, the average fraction of net precipitation (0.93 = 1.06 * 0.21 / 0.24) was always applied during modelling and determination of the water balance.

3.1 Determined water balance

The water balance and corresponding flows of water were expressed in L of water per area of substrate (L of water m^{-2} of substrate). It was expressed in this way, because the average maximum width of the trees was almost equal to the width of the substrate (appendix V, table 2).The water balance of three consecutive periods was determined. For the first period, from planting (April 23) till June 30, the input of water by irrigation was 53.9 L of water m^{-2} of substrate and input of water by precipitation was 158.6 L of water m^{-2} of substrate. The amount of water in the substrate was increased 38.9 L of water m^{-2} of substrate and the amount of water drained was 50.8 L of water m^{-2} of substrate. Based on these numbers, total evapotranspiration was calculated to be 122.8 L of water m^{-2} of substrate during this period (table 2). During this period, drainage was measured with help of jerry cans. A few times the jerry cans were totally filled on the moment of measuring. Thus these measurements were inaccurate. Drainage was underestimated, so evapotranspiration was overestimated.

During the month of July input of water by irrigation was 59.6 L of water m^{-2} of substrate. The input of water by precipitation was 87.4 L of water m^{-2} of substrate. 45.8 L of water m^{-2} of substrate was lost by drainage and the amount of water in the substrate was increased 11.5 L of water m^{-2} of substrate. For the month of July evapotranspiration was calculated to be 89.8 L of water m^{-2} of substrate (table 2)

For the month of August evapotranspiration was increased tremendously, 214.1 L of water m^{-2} of substrate was lost by evapotranspiration. The amount of water applied by irrigation was 201.0 L of water m^{-2} of substrate. The amount of water lost by drainage was 35.5 L of water m^{-2} of substrate and the input of water by precipitation was 48.6 L of water m^{-2} of substrate (table 2). For this period there was no net change in the amount of water in the substrate, since drainage occurred on July 31 and August 31. Therefore the substrate was assumed to retain the same amount of water on both dates, resulting in a net change of 0.0 L of water m^{-2} of substrate.

Table 2. Flows of water into and out from the substrate, including the net change in the amount of water in the substrate for three consecutive periods over time. Evapotranspiration was calculated for first year *Tilia* trees grown in the 'Dutch U system'.

	Input		Output		
Period (-)	Irrigation (L m^{-2} of substrate)	Precipitation (L m^{-2} of substrate)	Drainage (L m^{-2} of substrate)	Evapo-transpiration (L m^{-2} of substrate)	Change amount of water in the substrate (L m^{-2} of substrate)
April 23 - June 30	53.9	158.6	50.8	122.8	38.9
July	59.6	87.4	45.8	89.8	11.5
August	201.0	48.6	35.5	214.1	0.0

The block effect of the trees was already discussed in the part of the precipitation results. In case of other tree species, drainage was measured for the east and the west row whereby more drainage was observed in the west row compared to the east row, probably because of a higher input of precipitation. In case of the *Tilia* trees, water input by precipitation was only determined on the west row while drainage was only measured on the east row. This would mean that on average (average over the east and west row) real drainage would have been a bit higher than the determined drainage, while on average the real precipitation input would have been a bit lower. For this reason, evapotranspiration was probably overestimated during the determination of the water balance.

The results showed an increase of evapotranspiration over time, especially during the month of August. Evapotranspiration was 214.1 L of water m^{-2} of substrate during the month of August, which is an average evapotranspiration of almost 7 L of water m^{-2} of substrate d^{-1}. The high amount of water lost by evapotranspiration, was caused by the combination of warm weather during the month of August and the leaf area which was increased over the season (table 4). The average evapotranspiration of the *Tilia* trees during the month of August was lower than the average evapotranspiration of the nursery stock *Viburnum* grown in Florida (Beeson et al., 2010). *Viburnum* was grown in 11.4 l container pots, and evapotranspiration was on average 11.8 L of water m^{-2} of pot d^{-1}(for the whole growing season). The previous year, evapotranspiration of different nursery stocks grown in the 'Dutch U system' was around 6 L of water m^{-2} of substrate d^{-1} by the end of September (appendix I table 1). Therefore the evapotranspiration of the *Tilia* trees was assumed to be reasonable.

Crop coefficient Actual evapotranspiration of the *Tilia* trees (ET_C) and reference evapotranspiration of alfalfa (ET_0) was determined. Based on these results the crop coefficient (K_C) was calculated. Due to the increase of LA, the transpiring surface was increasing over time and thereby K_C was increased from 0.53 (-) on July 13 up to 1.92 (-) on August 25 (table 3). A maximum K_C value of 1.92 is in the expected range of K_C values, since it was lower than the upper limit of K_C of 2.5 (Allen et al., 1998) and also because it was lower than, or comparable to, K_C values of other crops grown in rows or pots and free stand trees (Orgaz et al., 2006; Pereira et al., 2011; Bacci et al., 2008). On July 13 the K_C value was 0.53, thus evapotranspiration was smaller than the K_C factor of 0.6 normally assumed for evaporation from bare soil (personal communication Pronk). According to Allen et al. (2005), evaporation could have a maximum K_C value of 1 when alfalfa is taken as reference crop. Because irrigation was applied regularly, the water content of the substrate was high during the current experiment and therefore evaporation was assumed to occur. Because the K_C factor was 0.53 on July 13 (and trees were already transpiring on this date), evaporation from the substrate of the 'Dutch U system' under bare conditions is assumed to be much lower than the K_C factor of bare soil. This might be realistic since on top of the substrate a layer of wood chip was applied (serving as mulch). Due to a layer of wood chip, evaporation of peat substrate was reduced approximately 40%, compared to pots with non-covered substrate (van Dalfsen and Pastoor, 2006). Evaporation from the small holes in the plastic airpot was probably not that high as well, since the holes were surrounded by a little layer of upstanding plastic. In this way air movement was partially blocked and thereby evaporation would be reduced (Allen et al., 1998).

Table 3. Crop coefficient (K_C) of *Tilia* trees grown in the 'Dutch U system' was determined at 5 different moments in time. To calculate K_C, actual evapotranspiration of the *Tilia* trees (ET_C) was divided by the reference evapotranspiration of alfalfa (ET_0)

Date of determination	Period of determination		ET_C (L m^{-2} of substrate)	ET_0 (L m^{-2} of substrate)	K_C (-)
	start	end			
July 13	July 9	July 18	15.9	30.2	0.53
July 23	July 20	July 27	34.1	35.8	0.95
August 4	August 1	August 7	41.3	26.1	1.58
August 14	August 9	August 20	74.6	51.0	1.46
August 25	August 21	August 30	67.4	35.1	1.92

3.2 Plant measurements

Interception of PAR and destructive harvest Destructive harvests were performed three times during the growing season, whereby different plant characteristics were determined. Specific leaf area (SLA) ranged between 127.0 cm^2 of leaf g^{-1} of leaf and 143.2 cm^2 of leaf g^{-1} of leaf (table 4). However, SLA did not differ significantly between the three dates (p = 0.520). Therefore, average SLA was used during model development, average SLA was 134.8 cm^2 of leaf g^{-1} of leaf. The width of the trees was increasing over time, on August 17 the width was maximal, 29.3 cm (table 4). LAI was increased from 0.86 (on June 26, up to 2.65 (m^2 of leaf m^{-2} of substrate) on August 17 (pictures can be found in fig. 5). On July 20 the LAI was determined and probably overestimated, since the destructively harvested plants were much taller than the plants measured for plant development (respectively 84.3 cm and 66.5 cm) (table 4, and appendix VI table 1). Because the destructively harvested plants were taller, LA was assumed to be overestimated as well.

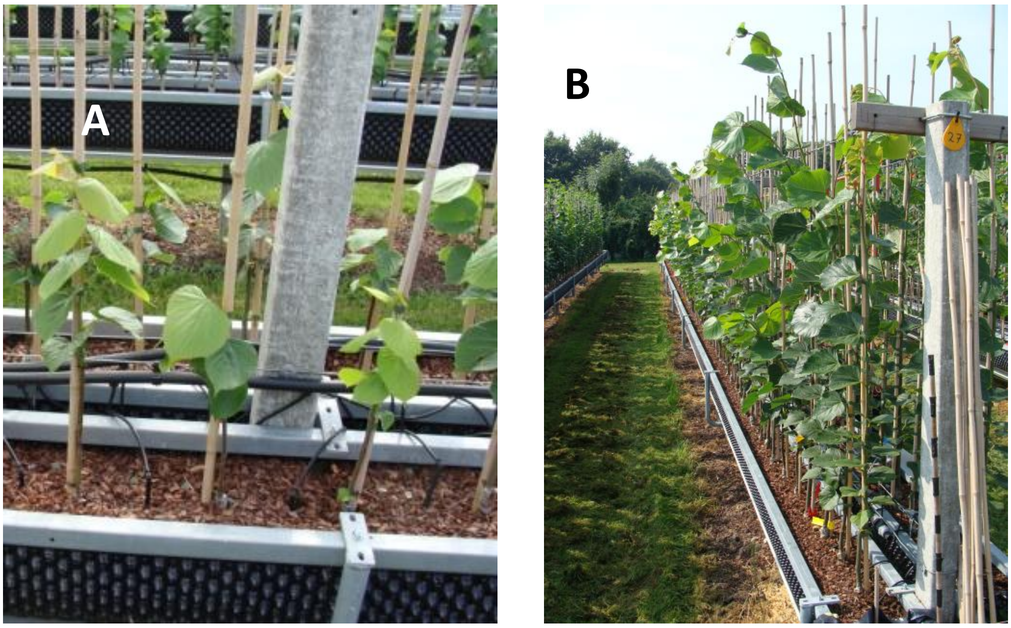

Fig 5. Two pictures of the *Tilia* trees grown in the 'Dutch U system'. Picture **A** was taken on June 26, picture **B** was taken on August 14.

The interception of PAR by the *Tilia* trees was increasing over time. On June 26 the percentage of interception of PAR was 0.29, for the measurement performed parallel to the row, and 0.36, for the measurement performed perpendicular to the row of the 'Dutch U system'. On September 4 the percentage of interception of PAR was increased up to 0.85 (parallel) and 0.78 (perpendicular) (table 5). Thus the percentages of PAR interception were a bit different between the two approaches of measuring the interception of PAR. Except of the measurements performed on August 17 and September 4, the percentage of interception of PAR was always lower in the case of the measurements performed parallel to the row. During the first four measurements the light was diffuse (due to clouds). Because the first leaves of the *Tilia* trees were located quite high on the stem, the row of *Tilia* trees was narrow and the path between the paired rows was wide, the measuring probe faced a small part of the sky (including the diffuse light). During the measurements performed parallel to the row, the whole probe was facing the sky. While during the measurements performed perpendicular to the row this effect was smaller, since only a small part of the probe was influenced by the diffuse light (only a small part of the beginning and the end of the probe, since the rest of the probe was not facing the path). During the two measurements performed lastly, the light was direct (no clouds) and the sun was straight above the trees. During these days the measurements performed parallel to the row were not influenced by the diffuse light coming from the path, while the measurements performed perpendicular to the row were more affected by the small open space between the two rows (more affected since all the light came from straight above the trees). For this reason on August 17 and September 4 the percentage of intercepted PAR was higher in case of the measurements performed parallel to the row.

Table 4. Average height, width, LA, LAI and SLA of a *Tilia* tree at three different moments in time. Values were determined by destructive harvest. Average values of three trees, standard deviations are shown between brackets.

Date	Height (cm)		Width (cm)	LA (cm^2)		LAI ($cm^2\ cm^{-2}$)	SLA ($cm^2\ g^{-1}$)	
June 26	41.3	(2.8)	18.0	414.7	(68.4)	0.86	127.0	(16.2)
July 20	84.3	(9.4)	26.2	1026.4	(192.0)	2.14	134.2	(19.3)
August 17	119.0	(14.9)	29.3	1273.6	(242.9)	2.65	143.2	(13.1)

Table 5. Average percentage of interception of PAR by *Tilia* trees grown in the 'Dutch U system', and calculated light extinction coefficient (k) of the *Tilia* trees, at different moments in time. Average interception of PAR was based on at least 30 measurements. Standard deviation is shown between brackets. Interception of PAR was measured parallel and perpendicular to the row.

Date	Diffuse or direct light	Percentage of PAR intercepted parallel (-)	Percentage of PAR intercepted perpendicular (-)	k (parallel) (-)	k (perpendicular) (-)
June 26	diffuse	0.29 (0.03)	0.36 (0.05)	0.39	0.51
July 10	diffuse	0.35 (0.03)	-	-	-
July 20	diffuse	0.43 (0.04)	0.54 (0.06)	0.26	0.44
August 6	diffuse	0.55 (0.06)	0.61 (0.05)	-	-
August 17	direct	0.72 (0.07)	0.68 (0.06)	0.48	0.56
September 4	direct	0.85 (0.05)	0.78 (0.07)	-	-

The light extinction coefficient (k) was determined using equation 4, three times during the growing season. Of the measurements performed parallel and perpendicular to the row average k was 0.38 and 0.50, respectively. Because the calculated interception of PAR was different between the two approaches, a different value of k was calculated. For both approaches, k was the lowest on July 20 (table 5), caused by an overestimation of the average LAI (explained before). Because equation 4 was used to calculate the value of k, an overestimation of LA leads consequently to an underestimation of k. The values of k found in the current research occurred to be realistic, since the k value of different Beech trees ranged between 0.30 and 0.63 and was on average 0.5 (Bartelink, 1998).

3.3 Model development

Because Brückner (1997) found that the EAW content (= WCFC – WCpF17) decreased only 3L of water 100 L^{-1} of substrate due to a compaction of substrate of 20%, and because pF = 1 was still 69% by the end of July , water-holding properties of the substrate were assumed to be constant over the season .

For the months of July and August, the development of LAI was predicted over time (fig. 6). To predict the development of LAI, equation 4 was used in combination with the measurements of interception of PAR and average value of k. The results of the parallel and perpendicular measurements were used to make the prediction of LAI. Based on the results of the parallel measurements, LAI was predicted to increase from 0.89 (begin July) up to 5.02 (end of August). In case of the measurements performed perpendicular to the row, LAI was predicted to increase from 0.87 on July 1, up to 2.96 (m^2 of leaf m^{-2} of substrate) on August 31 (fig. 6).

LAI will be predicted by the model. The prediction of LAI by the model is based on the results of the light measurements performed perpendicular to the row. This was done for two reasons. First, because the difference between determined- and predicted LAI was the smallest in case of the prediction of LAI was based on the interception of PAR measured perpendicular to the row (appendix VI., table 2). Second, because when the prediction of LAI was based on the measurements performed parallel to the row, the prediction of LAI reached a value of 5 on August 31 (fig 6). A value which is unreasonably high compared to the LAI determined on August 17 (table 4). Between the paired rows were wide grass paths. Due to these wide paths, the lowest leaves of the *Tilia* trees were able to intercept radiation as well For this reason the shading effect of the canopy of the trees was assumed to be small. Therefore, LAI was assumed to increase linearly over time for the period from July 1 until August 31.

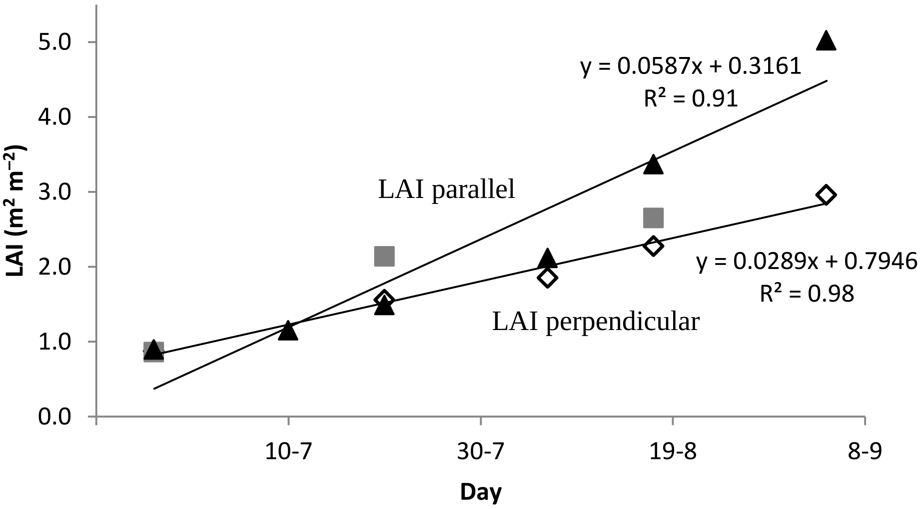

Fig. 6. Leaf area index (LAI) of *Tilia* trees grown in the ‘Dutch U system’. The interception of PAR was measured parallel and perpendicular to the row of the *Tilia* trees, based on these results LAI was predicted. The determined LAI (determined by destructive harvest) is presented by the grey blocks.

Daily total radiation (DTR) in combination with the percentage of interception of light and increase in weight of LA, was used to determine the light use efficiency (LUE). PAR was set to be equal to half of the DTR (Million et al., 2011). For the period of June 26 until August 31, average LUE was 0.46 (g dry matter of leaves MJ^{-1} of PAR). Because the growth of the trees had less interest in the current research, LUE was only determined for increase in leaf weight. In this way an additional source of deviation was not included in the model as well. For the calculation see appendix V. In case of the current experiment, the increase of leaf weight was only 30% of the total increase of shoot biomass (dry weight). In the CCROP model of Million et al. (2011) 10% of the daily biomass gain was partitioned to the roots. If the LUE of the *Tilia* trees of the current research was converted to g of dry matter production MJ^{-1} of PAR, LUE would have been approximately: 0.46 * (1.1 / 0.3) = 1.7. A LUE which is smaller than the LUE of 2.8 g MJ^{-1} of PAR of the nursery stock *Viburnum odoratissimum*

(Million et al., 2011). But the LUE found in the current research was larger than the LUE of 1.25 found for a deciduous forest (including *Tilia* species) in North Carolina, USA (Pangle, 2003). Therefore the LUE found was assumed to be realistic.

K_C was correlated to LAI and showed a significant (P = 0.016) linear relationship (fig 7). The intercept was not significantly different than 0 (P = 0.302). However, based on the performance of the model, the intercept of the equation is used in the model to predict K_C. Even an intercept of 0 is an unrealistic number, since evaporation from the substrate will occur if no crop is grown (Allen et al., 2005). The correlation was made for a period of the growing season were the trees already had LA at the start. Therefore an intercept of 0 is not that strange, because the effect of evaporation is already processed in the K_C factor, since evapotranspiration is calculated by the Penman – Monteith equation. To be able to apply the model more easily to other tree species and cultivation systems, evaporation and transpiration can be predicted separately based on the dual crop coefficient (Allen et al., 1998). In the CCROP model of Million et al. (2011), potential evaporation of the substrate and potential transpiration of the trees was determined. Based on the development of LAI, the influence of evaporation was reduced and the influence of transpiration was increased. To apply such a procedure more research is needed, but thereby the general applicability of the model will be improved. Evapotranspiration was assumed to be non-water limited during the determination of the water balance. It was proposed to test this assumption with help of the little rows, but the trees in the little rows were to less developed compared to the trees in the large rows of the 'Dutch U system'. Therefore the test was not performed in this way. According to Million et al. (2011), reduction in ET_C occurs when actual EAW drops below 50% of maximum EAW. Therefore, in the current experiment reduction of ET_C was assumed to occur if the amount of water in the substrate becomes lower than 101.7 L of water m^{-2} of substrate (= (0.69 + 0.44) / 2 * 180). At pF = 1 the amount of water in the substrate was 124.2 L of water m^{-2} of substrate (= 0.69 * 180). Because the little rows were not used, ET_C was determined for a period between two drainage events. The day the second drainage event occurred, the difference in the water content of the substrate was determined. The water output from the substrate was subtracted from the water input into the substrate and the difference was assumed to be the change in the amount of water in the substrate (for that period). In all cases the change was not larger than 10 L of water m^{-2} of substrate. 50% of EAW was equal to 22.5 L of water m^{-2} of substrate (124.2 – 101.7), thus much larger than the calculated change in the amount of water in the substrate. For this reason ET_C was assumed to be non-water limited.

3.4 Performance of the model

Based on the weather data, the water balance of the period from June 1 until August 31 was simulated. The results of the simulation are presented in table 6. Irrigation was given as input variable and for this reason the application of irrigation was exactly equal to the irrigation of the determined water balance. Inputs of water by precipitation was a forcing function in the model. Therefore the outcome of the simulation was equal to the inputs of precipitation in the determined water balance, since in both cases the input of precipitation was set to be 93% of gross precipitation.

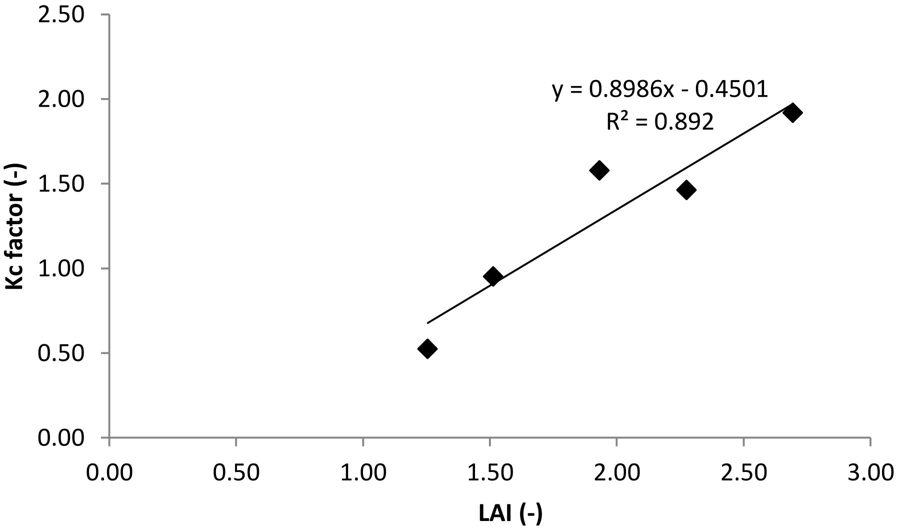

Fig. 7. The crop coefficient of the *Tilia* trees grown in the 'Dutch U system' (Kc) correlated to the LAI of the *Tilia* trees.

Table 6. Flows of water into- and out from the substrate, including the change in the amount of water in the substrate, modelled by the developed model for two different time periods (total is the summed water balance of the two periods). Evapotranspiration was calculated for first year *Tilia* trees grown in the 'Dutch U system'.

	Input		Output		
Period (-)	Irrigation ($L\ m^{-2}$ of substrate)	Precipitation ($L\ m^{-2}$ of substrate)	Drainage ($L\ m^{-2}$ of substrate)	Evapo-transpiration ($L\ m^{-2}$ of substrate)	Change in amount of water in the substrate ($L\ m^{-2}$ of substrate)
July	59.6	87.4	46.1	90.6	10.2
August	201.0	48.6	47.2	201.9	0.6
Total	260.5	136.1	93.3	292.5	10.8

Evapotranspiration (ET_C) was calculated using the weather data and development of LAI. For the month of July there was a little difference between the simulated and determined amount of water lost by ET_C, 90.6 and 89.8 L of water m^{-2} of substrate, respectively (table 2 & 6). The difference between the determined and simulated ET_C was larger for the month of August. The determined ET_C was 214.1 L of water m^{-2} of substrate (table 2), while an ET_C of 201.9 L of water m^{-2} of substrate (table 6) was simulated. An underestimation of 6.0%. Over the whole period, simulated ET_C was underestimated by less than 4%. Therefore, it was concluded that ET_C was simulated well by the model. The error between simulated- and determined ET_C was comparable to the results obtained by Gallardo et al. (2011) in modelling ET_C of muskmelon. Kirnak et al. (2002) evaluated different formulas simulating ET_C of the nursery stock *Acer Rubrum* for a two month period. Compared to the outcome of these calculations the performance of the current model was better. The smallest error in estimating ET_C, as found by Kirnak et al. (2002), was 15%. Drainage is the other way of losing water from the substrate, due to the underestimation of ET_C, drainage was overestimated as a consequence. ET_C was underestimated 11.4 L of water m^{-2} of substrate, while drainage was overestimated 11.7 L of water m^{-2} of substrate (table 2 & 6).

The K_C factor was simulated well by the model (fig. 8 A&B), but ET_C was underestimated. Due to the difference in weather and LAI development, the actual difference between simulated and determined ET_C will differ year to year. For this reason, the fact that simulated and determined ET_C of the month of July was so close, was mainly caused by coincidence. If e.g. the under- and overestimation of K_C had a different pattern compared to the pattern shown in fig. 8, ET_C might have been overestimated. Allen et al. (1998) indicated that the risk of overestimating ET_C is increased at higher K_C values, something that was not observed in case of the current research.

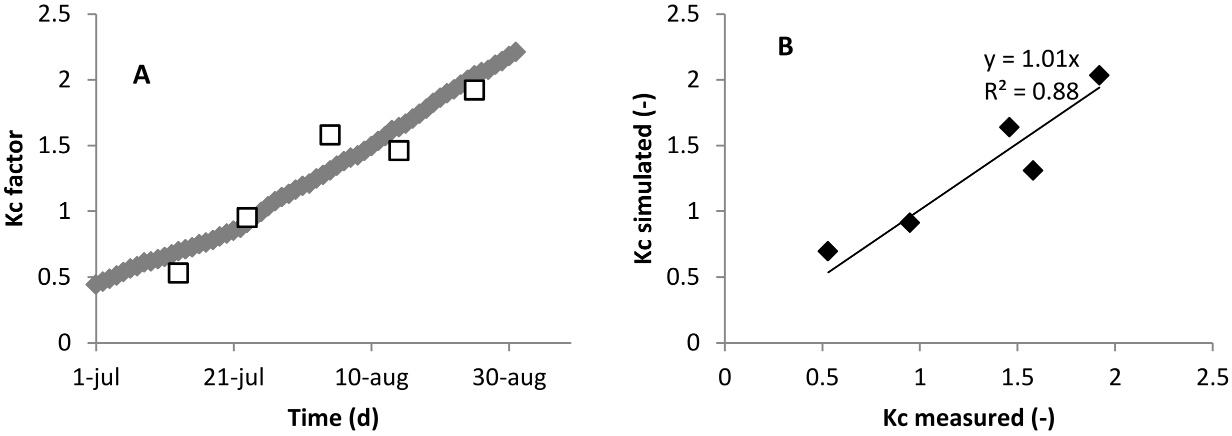

Fig. 8. A. Crop coefficient (Kc) of Tilia trees grown in the 'Dutch U system' simulated by the model as a function of time. The open blocks represent the calculated Kc factors.
B. Simulated (by the model) versus calculated (based on determined evapotranspiration of the water balance) Kc factor of *Tilia* trees grown in the 'Dutch U system'.

The model was also run with weather data of 2011 from July 1 until August 31. Because in 2011 *Tilia* trees were grown in combination with different tree species in one row, the water balance was not determined. For this reason it was not possible to assess the performance of the model in simulating the water balance of 2011. During the season of 2011 the amount of precipitation was much higher. The total input of precipitation was 252.8 L of water m^{-2} of substrate. The input of water by irrigation was automated and was calculated to be 81.0 L of water m^{-2} of substrate. Simulated evapotranspiration was 191.7 L of water m^{-2} of substrate and the amount of water lost by drainage was 138.3 L of water m^{-2} of substrate. The amount of water in the substrate was increased by 3.8 L of water m^{-2} of substrate. Evapotranspiration and input of precipitation of 2011 were different compared to both flows of 2012, but the numbers looked like to be realistic. Nevertheless, no statement about the performance of the model simulation of 2011 could be made. Unfortunately, because if the model simulated the water balance of 2011 well, more about the general applicability of the model under different growing conditions could have been concluded.

3.5 Sensitivity analysis

Different parameters and input variables were increased by 10% to perform a sensitivity analysis on ET_C. The effect on simulated ET_C was never larger than 10% (fig. 9), indicating that the simulation of ET_C is relatively robust to changes in the values of the parameters and input variables (Zuidema et al. 2005). According to Zuidema et al. (2005), a promising result, since the model does not predict unrealistic changes in ET_C due to small changes in the input variables and parameters. If the different parameters and input variables were decreased by 10%, the percentage of change in simulated ET_C was comparable to the results of increasing the values of the input variables and parameters by 10%. Due to a 10% increase of the different input variables and parameters, simulated ET_C was increased in all cases, except of the variables relative humidity and soil heat flux (fig. 9).

Relative humidity had the largest effect on ET_C, the effect of K_C was almost the same (fig. 9 & table 7). Because of the humid conditions of the Dutch climate the calculation of ET_C wasmore sensitive to relative humidity (Meyer et al., 1989; Estévez et al. 2009). Probably relative humidity appears only in the nominator of equation 2, while wind appears in the denominator as well. However, the sensitivity coefficient of the different weather parameters showed seasonal variation or variation between different climatic locations, due to differences in the weather variables (Ali et al., 2009; Estévez et al. 2009). Therefore the sensitivity of the calculation of ET_C to the weather can differ between different growing seasons. An increase of SLA or LUE had exactly the same effect on simulated ET_C, since both parameters are multiplied by each other to calculate the increase of LAI. Due to an increase in K_C, SLA and LUE, simulated ET_C was affected by the reduction factor of evapotranspiration during the period of simulation, since the water content of the substrate was decreased below the reduction threshold of 50% EAW on some moments. In general the model was more sensitive to increased parameters of the trees related to transpiration than to increased weather variables. A result comparable to the research of Satti et al. (2004): ET_C of potatoes and ferns were most sensitive for changes in the K_C value as well.

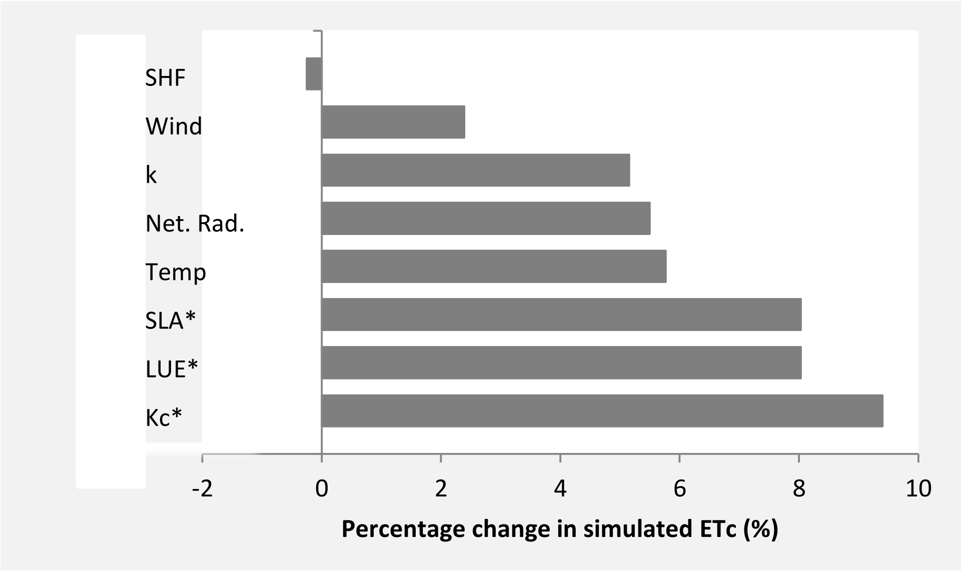

Fig. 9. Results of the performed sensitivity analysis on evapotranspiration (ETc) of *Tilia* trees grown in the 'Dutch U system'. Therefore, the value of a parameter or variable was increased by 10%, the percentage of change in ETc is shown. Adapted parameters were: SHF (soil heat flux); Wind (wind); k (light extinction coefficient); Net. Rad. (net radiation); Temp (temperature); SLA (specific leaf area); LUE (light use efficiency); and Kc (crop coefficient).
* ETc was reduced a few times during the simulation, because a few times the water content of the substrate was decreased below 50% of EAW.

Due to a 10% decrease of irrigation or a 10% decrease of the percentage of precipitation entering the substrate, drainage was reduced (table 7). The absolute reduction of drainage was exactly the same as the absolute decrease of input of water. If both inputs of water were decreased by 10%, the reduction in drainage was even larger and reduction in ET_C did not occur (fig. 6). When the moments of irrigation were determined by the model (automated irrigation), the input of water by irrigation was reduced by 25%, compared to the total amount of irrigation applied in the current research. Due to automated irrigation, ET_C was not negatively influenced (table 7). An indication of the relevance of the developed model to explore the possibilities to reduce the water use during the production of nursery trees in the 'Dutch U system', e.g. by testing different strategies of irrigation or to automate irrigation. An important result in relation to the goal of the project 'Teelt de grond uit' with respect to the reduction of the amount of water used. When the water content of the substrate at pF = 1 was decreased by 10% (e.g. due to compaction of the substrate or when another substrate is used), drainage was increased and ET_C was decreased (table 7). The increase in drainage was caused by the smaller water holding capacity of the substrate. Thus a substrate having a larger volume, larger water content at pF = 1 or larger EAW results in a more stable system, since the chance of having drainage or drought stress is reduced. Nevertheless, ET_C was reduced by less than 2%, due to a 10% decrease of the water content of the substrate at pF = 1. Therefore, evapotranspiration was not very sensitive to changes in the characteristics of the substrate. For this reason it was of minor importance to adjust WCFC in the model during the season. Also Million et al. (2011) did not make use of a reduction of Vol.% of water of the substrate at pF = 1 during the simulated growing season.

Table 7. Simulated flows of water into- and out from the substrate, including the change in the amount of water in the substrate. The water balance was simulated from July 1 until August 31. Evapotranspiration was calculated for first year *Tilia* trees grown in the 'Dutch U system'. Different parameters of the model were decreased by 10%: Default values, none of the parameters were decreased; Rel. hum., relative humidity was decreased by 10%; Irrigation, irrigation was decreased by 10%; Fr. rain, the percentage of precipitation entering the substrate was decreased by 10%; WCFC, the water content of the substrate at pF =1 was decreased by 10%; Irrigation + Fr. Rain, both, irrigation and the percentage of precipitation going into the substrate were decreased by 10%; and Irrigation automated, none of the parameters were decreased, but moments of irrigation were determined by the model.

	Input		Output		
Decrease parameter of 10% (-)	Irrigation (L m^{-2} of substrate)	Precipitation (L m^{-2} of substrate)	Drainage (L m^{-2} of substrate)	Evapo-transpiration (L m^{-2} of substrate)	Change amount of water substrate (L m^{-2} of substrate)
Default values	260.5	136.1	93.3	292.5	10.8
Rel. hum.	260.5	136.1	60.5	325.5	10.7
Irrigation	234.5	136.1	67.4	292.4	10.7
Fr. rain	260.5	122.5	79.0	292.4	10.7
WCFC	260.5	136.1	108.9	287.7	0.0
Irrigation + Fr. rain	234.5	122.5	54.0	292.2	10.7
Irrigation automated	193.5	136.1	35.0	292.5	2.1

3.6 Future of the model

The water balance was determined, and based on these results a model was developed. The amount of precipitation entering the substrate was a fixed percentage of gross precipitation. However, due to larger rainfall events the percentage of precipitation input appeared to be larger, so precipitation was probably underestimated during larger rainfall events. Thus the actual percentage of precipitation going into the substrate has to be investigated further. Further research needs to be done on an hourly time interval, so the data can be applied directly to the model. The effect on the water balance of an improved estimation method of the input of precipitation would have be relatively small in the current year, since irrigation was the main source of water input into the substrate. However, since a reduction of precipitation input directly caused a reduction of drainage or in other seasons the amount of precipitation could be higher (e.g. 2011), improvement of the estimation method of the input of precipitation is necessary.

In the current model, intercepted precipitation by the leaves did not reduce the amount of water lost from the substrate by evapotranspiration. An assumption comparable to the LINTUL-2 model, where leaves were assumed to be dry by the beginning of every new day (modelled on 1 day interval) (van Ooijen and Leffelaar, 2008). But it is an assumption which is more unrealistic in case of a model based on an hourly time interval. E.g. in the current research maximum interception was assumed to be 0.25 L of water m^{-2} of leave, while simulated hourly ET_C was smaller than 0.25 * LAI many times. For this reason the assumption of dry leaves on the beginning of every hour is not always realistic. Therefore it was proposed to subtract the amount of intercepted precipitation from calculated $ET_{C,}$ as was done by Gash (1979), since first the intercepted precipitation will transpire before transpiration of the wetted leaf surface will occur. Nevertheless, this concept was not applied in the current model, since during the determination of the water balance, evapotranspiration was not compensated for the reduction in evapotranspiration caused by the transpiration of intercepted precipitation as well (actually the same holds for the condensation of water on the leaf surface). However, to be able to use the model in different seasons, it might be useful to include the module of interception of precipitation of Gash (1979) in the current model. Because in this way the effect of dry or wet seasons on ET_C can be compensated by the model. On the other hand, the effect will be relatively small compared to the total water balance.

ET_C was predicted very well, since it was underestimated less than 4% for the period from July 1 until August 31. Based on the performed sensitivity analysis, ET_C was most sensitive to the K_C factor or plant characteristics related to the prediction of K_C (LUE, SLA). This result was supported by the results of Satti et al. (2004). Therefore, during the improvement of the model, or adjusting of the model to other tree species, additional focus needs to be given to the crop coefficient. According to Derkx (2011), determined crop coefficients of different nursery stocks were only applicable under the specific growing- and cultivation conditions of determination. Something that also will hold for the determined K_C factor of the current experiment. To enhance the general applicability of the developed model, the dual crop coefficient can be applied. The crop coefficient will be split into two separate crop coefficients, one for crop transpiration and one for soil evaporation (Allen et al., 1998). Due to the dual crop coefficient in combination with the correlation of the crop coefficient to LAI, the calculation of ET_C will become independent of the cultivation method, like e.g. cultivation system and plant distance. A method also applied in the models of Million et al. (2011) and Orgaz et al. (2006). Crop coefficients need to be determined in comparable climatic conditions, since significant errors in estimation of ET_C can occur when crop coefficients are determined in totally different climatic conditions (Jagtap and Jones, 1989). In the current research K_C was based on the area of the substrate, but when the canopy area of other tree species is much wider than the area of substrate in future research, ET_C can be expressed per canopy area as well (Beeson, 2004).

An alternative approach to estimate ET_C might be to adapt the parameters of the FAO P-M equation to a tree canopy, so ET_0 of a reference tree will be determined. Then ET_C of other tree species can be determined using ET_0 of a reference tree and corresponding K_C factor. Verbeeck et al. (2007) used another approach: transpiration per leaf area was determined and was scaled up to the transpiration of the entire tree based on leaf area. Because both approaches already take into account the clothesline- and oasis effect during the calculation of ET_0, both might be a good alternative to calculate ET_C instead of making use of the current FAO P-M equation. On the other hand, ET_C was simulated well and ET_C of nursery stock or row crops is estimated generally by making use of grass or alfalfa as reference crop (e.g. Koerselman and Beltman, 1988; Allen and Pereira, 2009; Million et al., 2011; Irmak, 2005).

Growth and production models have shown to be very useful in improving cropping systems, because insight in the cropping system was provided (Zuidema et al., 2005). In the same way the current model can be useful to explore the possibilities to reduce nutrient emissions and water use of the ‘Dutch U system’, especially because emission reduction was the main goal of the project ‘Teelt de grond uit’. To be able to explore the possibilities to reduce the emission of nutrients, the developed model has to be extended by a subroutine for nutrients, as e.g. was done in the CCROP model of Million et al. (2011). To simulate the nutrient use also a subroutine of plant growth will be necessary, as e.g. was done by Million et al. (2011) and Zuidema et al. (2005). An useful module, because in this way the nutrient use of the trees can be simulated and evapotranspiration can be correlated to the growth of trees. An approach that already was applied in the current model based on LAI.

Another possibility of using the model is to automate the application of irrigation. In contrast to the growing of nursery stocks, irrigation is already highly automated in greenhouse cultivation (Derkx, 2011). Nevertheless, Million et al. (2011), Beeson jr. (2010) and Beeson (2004) already have developed different models to automate the irrigation in case of different nursery stocks grown in pots. Compared to the applied irrigation in the current experiment, due to automated irrigation, simulated application of irrigation was 25% lower and ET_C was not reduced. However, before irrigation can be fully automated, it has to be known better at which water content of the substrate the growth of different tree species are reduced. Even Million et al. (2011) had to continue the testing of the water stress functions. Something that can be tested by growing the trees under different watering regimes. If irrigation is automated a module adjusting the model to the influence of management practices is needed, since production and management practices can cause large differences in ET_C of the same crop in the same region (Stegman, 1988). In case of the cultivation of nursery stock, management practices can be e.g. pruning or spacing of the pots (Million et al., 2011; Beeson jr., 2010). The *Tilia* trees were not pruned in the current research, but pruning might be necessary in case of other tree species grown or an extended period of simulation. Therefore, a management module will be useful, so the model can be adapted easily to other tree species and/or cultivation systems. The combination of a crop management module, as used in the CCROP model of Million et al. (2011), and a crop coefficient correlated to LAI (as used in the current model), is useful to adjust the simulation of evapotranspiration to the effect of management practices on evapotranspiration.

4. Conclusion

The aim of the current research was to determine and model the water balance of *Tilia* trees grown in the 'Dutch U system'. The water balance was determined and showed reasonable results. During the month of August evapotranspiration was on average 6 L of water m^{-2} of substrate d^{-1}. The high percentage of precipitation entering the substrate was unexpected. The water balance was simulated very well by the model. Evapotranspiration was underestimated 4%. Input of precipitation into the substrate was a fixed percentage of gross precipitation, both during the determination and modelling of the water balance. However, based on the measurements of input of precipitation, a fixed percentage of precipitation input might not be realistic. Nevertheless, a fixed percentage of input of precipitation was used in the model, since it was not possible to convert the daily precipitation data into hourly precipitation data and no clear pattern was found to come up with an improved estimation method of the input of precipitation. For this reason more detailed research on the input of precipitation is needed, especially on an hourly interval.

Thus a basic model of the water balance of the 'Dutch U system' was produced, a model which can be adapted easily to other tree species. Based on the sensitivity analysis, main attention needs to be given to the determination of the parameters related to the crop coefficient (so in case of the current research SLA, LUE and K_C) during the improvement of the model or adaptation of the model to other tree species, since changes in these parameters had the largest effect on ET_C. Relative humidity was the weather parameter having the largest effect on ET_C in the current research. Due to automated irrigation, irrigation was decreased by 25% compared to the amount of irrigation applied in the current experiment. Therefore, the developed model is an useful tool to explore different possibilities to reduce the water use and nutrient emissions of the 'Dutch U system'. To be able to use the model for these tasks, the model needs to be extended by additional modules, as e.g. a management and nutrient module.

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Appendix I. Results of previous year

Table 1. The water balance and calculated average K_C value for four tree species grown in the 'Dutch U system' during the dry period of September 24-26, 2011.

Species	Irrigation	Drainage	Diff. amount of water substrate*	ET_C **	Area substrate	ET_C	ET_C (per day)	ET_0 (alfalfa)*** per day	K_C
	(L of water substrate^{-1})	L of water substrate^{-1})	L of water substrate^{-1})	L of water substrate^{-1})	(m^2)	(L m^{-2})	(L m^{-2} d^{-1})	(L m^{-2} d^{-1})	-
Robinia and Cercidiphyllum	96.8	1.0	–22.0	117.8	6.0	19.6	6.5	2.6	2.5
Zelkova	95.5	9.9	–22.0	107.6	6.0	17.9	6.0	2.6	2.3
Carpinus	81.0	2.9	–22.0	100.1	6.0	16.7	5.6	2.6	2.2

* Difference in water content of the substrate was measured and multiplied by the volume of the row of the 'Dutch U system'.

** To calculate ET_C, drainage and the difference in the amount of water of the substrate was subtracted from the water input by irrigation.

*** ET_0 was determined by making use of the FAO Penman-Monteith equation, alfalfa was taken as reference crop.

Table 2. LAI (expressed per field- and canopy area), average K_C value (period September 24-26 2011) and fraction K_C per LAI for four tree species. To calculate K_C, ET_C was divided by ET_0. LAI was determined by Pronk (personal communication).

Species	LAI (field area)	LAI (canopy area)	K_C	K_C / LAI (field area)
	(m^2 m^{-2})	(m^2 m^{-2})	-	-
Robinia	3.45	7.22	2.5	0.7
Cercidiphyllum	1.45	3.28	2.5	1.7
Zelkova	0.86	1.77	2.3	2.7
Carpinus	0.74	2.00	2.2	2.7

Appendix II. Water balance scheme

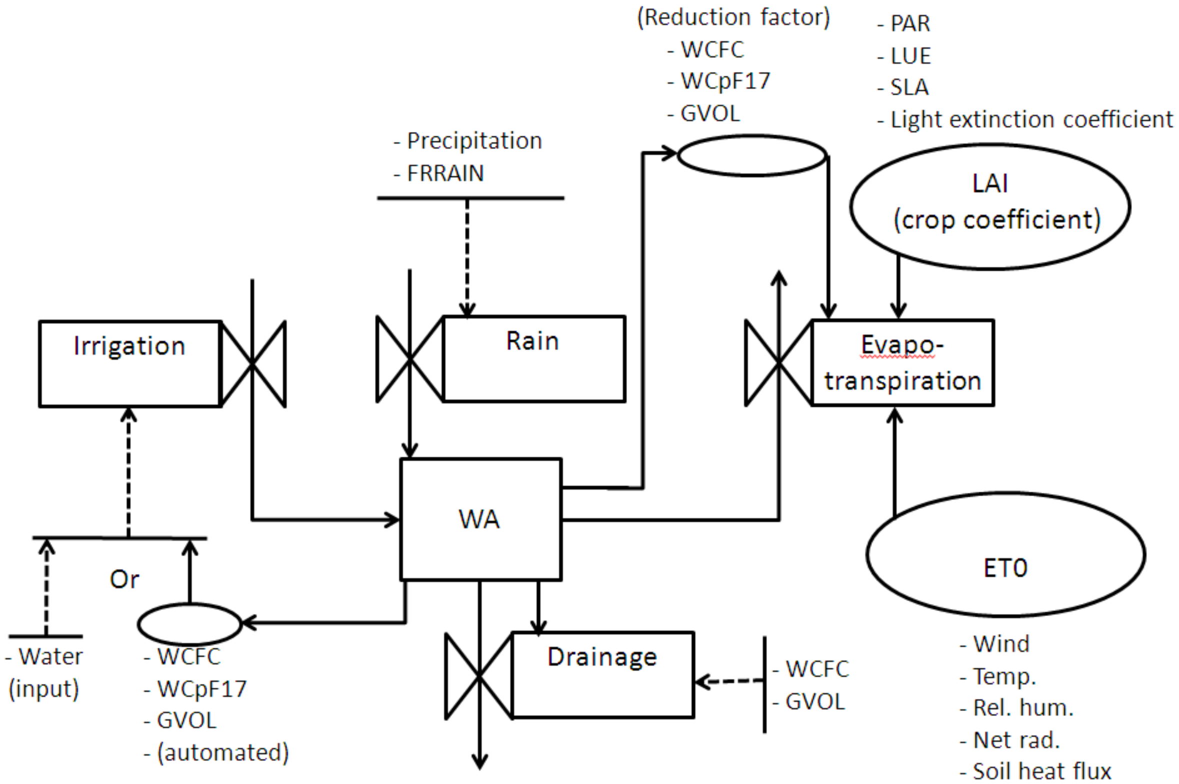


Fig 1. Conceptual representation of the model. The amount of water in the substrate is the state variable (WA). Irrigation and rain (precipitation) are the rates of water entering the substrate. Drainage and evapotranspiration are the rates of water leaving the substrate. Irrigation is given as input variable, also a module of automated irrigation is developed. However, only one of the two options can be switched on per run. To calculate the input of water by rain, precipitation (input variable) is multiplied by the percentage of precipitation entering the substrate. Evapotranspiration is calculated using calculated reference evapotranspiration and a changing crop coefficient. If the amount of water in the substrate is below a threshold, evapotranspiration will be affected by a reduction factor. The crop coefficient is developing over time and is correlated to LAI. If drainage occurs depends on the amount of water in the substrate, the characteristics of the substrate and the other rates of water leaving and entering the substrate. The meaning of the different abbreviations, and more detailed information, can be found in material and methods. The model runs on an hourly time interval.

Appendix III. FAO Penman-Monteith, supportive equations

Some variables of the FAO Penman-Monteith equation were calculated by additional equations, used equations were:

Δ is calculated with the formula from Nandagiri and Kovoor (2005):
$\Delta =(4098*0.6108e^{((17.27*T)/(T+237.3))})/ (T+237.3)^2$ (kPa ˚C^{-1})

Saturation vapour pressure was not measured by meteostation Veenkampen. Therefore, actual vapour pressure (e_s) wass calculated using the formula of Nandagiri and Kovoor (2005):
$e_s = 0.6108e^{((17.27*T)/(T+237.3))}$ [kPa]

γ also based on a formula from Nandagiri and Kovoor (2005):
$\gamma = 0.665 E\text{-}3 * P$ (kPa ˚C^{-1})

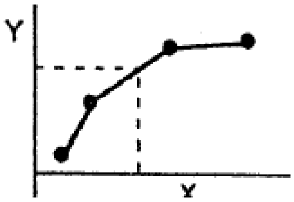
P is calculated with the formula from Nandagiri and Kovoor (2005):
$P = 101.3 * ((293 - 0.0065z) / 293)^{5.76}$ (kPa)
z = elevation above sea level (m) (Wageningen as reference: z = 7m)

Resulting in an γ of 0.067 kPa ˚C^{-1}

Appendix IV. Used functions of FST language

Three different functions of FST language were used. The description is give below. The information was taken from van Ooijen and Leffelaar (2008).

Mathematical notation or graph	FST function
$y(t)=y(0)+\int_0^t \frac{dy(t)}{dt}dt$	`Y = INTGRL(YI , RY)` Integration command in the form of a function call. The algorithm of the numerical integration depends on the selected translation mode (Euler or Runge-Kutta). `Y` state variable `YI` initial value of Y `RY` rate of change of Y

	`Y = AFGEN(F , X)`
	Linear interpolation between (`x`, `y`) function points.
	`Y` result of interpolation, estimated `F(X)`
	`F` Table of `(X,Y)` values specified with a `FUNCTION` statement
	`X` value of independent variable
	
	In the `FUNCTION` statement, the `X` in the `(X,Y)` pairs must continuously increase, so in the definition
	`FUNCTION F = (X1,Y1),(X2,Y2),(X3,Y3),...`
	`(X4,Y4), (X5,Y5)`
	`X1 < X2 < X3 < X4 < X5`.

$\left\{\begin{matrix} y=y_1, x<0 \\ y=y_2, x\geq 0 \end{matrix}\right\}$	`Y = INSW(X, Y1, Y2)`
	Input switch. `Y` is set equal to `Y1` or `Y2` depending on the value of `X`.
	`Y` returned either as `Y1` or `Y2`
	`X` control variable
	`Y1` returned value of `Y`, if `X`<0
	`Y2` returned value of `Y`, if `X`≥0

Appendix V. Calculations and conversion of units

Calculations:

Calculation of EAW per m^2 of substrate The length of a row was 24 m, the width of the a row was 0.24 m. The width of the plastic airpot used was 0.60 m.

- Therefore, assumed depth and width of the substrate were 18 and 24 cm (18+24+18=60), respectively.

Characteristics of the used substrate were determined by Blgg Agroexpertus. The water content of the substrate at field capacity (pF 1) was 69 Vol.%. Easy available water uptake (EAW) is between pF 1 and pF 1.7. The water content at pF 1.7 is 44 Vol.%. Thus EAW is 25 Vol. % (69 – 44)

Volume of the substrate: 24 * 0.18 * 0.24 = 1.04 m^3
Volume per m^2 of row: 1.04 / (24 * 0.24) = 0.18 m^3 of substrate m^{-2} of row
= 180 L
EAW per m^2 of substrate: 180 * 0.25 = 45.0 L

Water content substrate before planting Characteristics of the used substrate were determined by Blgg Agroexpertus. The bulk density of dry substrate was 130 kg of substrate m^{-3} of substrate. The dry weight of the substrate was only 24% of the total weight of the delivered substrate. Thus 76% of the weight of the delivered substrate was water (table 1).

Table. 1 Properties of substrate as before planting, analysis performed by Blgg Agroexpertus.

	Water (weight0, water and air (volume)	Substrate
Weight %	76	24
Vol. %	92	8
Bulk density (kg m^{-3})		130

Based on the these results, the amount of water in the deliverd substrate was calculated:
Amount of water of the substrate: (130 / 24) * 76 = 412 kg m^{-3}
Thus the water content of the substrate was 41 Vol. % before planting.

Determination of LUE First the fraction of light interception (level of PAR below the *Tilia* canopy was divided by the reference level of PAR, and this was subtracted from 1), measured perpendicular to the row, was plotted over time (fig. 1.). Based on the formula of the trend line, the average daily interception of PAR was calculated.

The fraction of intercepted PAR was calculated with the formula: 0.0059 * day + 0.3683
E.g. fraction of intercepted PAR on June 26 = 0.0059 * 1 + 0.3683 = 0.37. Fraction of PAR interception on September 4 was 0.79.

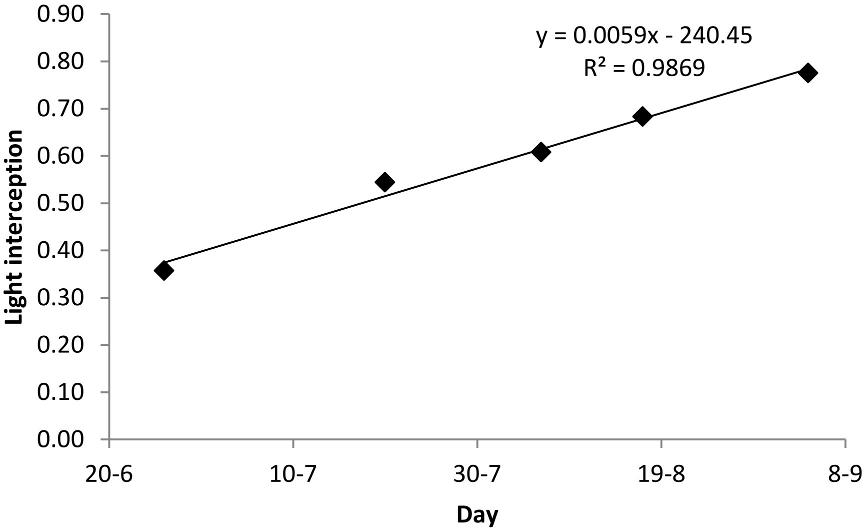


Fig. 1. Fraction of intercepted PAR, by *Tilia* trees grown in the 'Dutch U system', over time.

Total daily radiation was 227.6 W m^{-2} on July 1
Intercepted PAR = ((227.6 * 0.5) * 86400 / $1*10^6$) * .37 = 3.6 MJ m^{-2} d^{-1}
For the period of June 26 until September 4, the total amount of shortwave radiation intercepted was 349.8 MJ m^{-2}. Daily interception of PAR was calculated and summed for the period from June 26 until September 4.

With help of the trend line of fig. 1, interception of PAR was determined for June 26 and August 31. The interception of light was known, 0.37 and 0.79 on June 26 and September 4, respectively. To determine LAI, equation 4 was changed into:

LN(1 – light interception) / –k

The k value was determined in the results and discussion chapter, and was applied in the calculation. The determined value of k was 0.505.
On June 26 LAI was 0.91, on September 4 LAI was 3.06.

Then LUE was determined. LUE was only determined for leaf production. The formula used was:

(LAI (Sept. 4) – LAI (June 26)) / (SLA / 10000) / total shortwave radiation intercepted
LUE = (3.06 – 0.87) / (134.8 / 10000) / 349.8 = 0.46 g of leaves MJ^{-1}

Conversion of units:

W m^{-2} = J s^{-1} m^{-2}
= 3600 J h^{-1} m^{-2}
= 86400 J d^{-1} m^{-2}

Appendix VI. Additional results and statistical outcomes

Plant height During the growing season plant height, the width of the trees perpendicular to the row and the width within the row were determined different moments in time (table 1). On June 12 the average perpendicular width of the *Tilia* trees was higher than the average perpendicular width on July 3, because the trees were pruned and bound to the trellis on June 20. On June 20 the trees were pruned and bound to the trellis, which caused the decrease in perpendicular width.

Table 1. Average height of a *Tilia* tree, average maximum plant width- perpendicular to the row and within the row, at different moments in time. Average values of ten trees.

Date	Height (cm)	Width perp. row (cm)	Width within row (cm)
June 12	29.7	26.1	-
July 3	49.4	18.5	16.9
July 20	66.5	24.7	23.5
August 14	118.3	24.9	23.3

LAI The leaf area index (LAI) was determined by a destructive harvest three times during the growing season. Based on the interception of light and the extinction coefficient, LAI was predicted for these dates as well (table 2).

Table 2. Leaf area index (LAI) measured and predicted, -based on two different kinds of measurement of interception of light performed (perpendicular and parallel)-, on three different moments in time.

Date	LAI measured (m^2 of leaf m^{-2}of leaf)	LAI perpendicular (predicted) (m^2 of leaf m^{-2}of leaf)	LAI parallel (predicted) (m^2 of leaf m^{-2}of leaf)
June 26	0.86	0.87	0.89
July 20	2.14	1.85	1.49
August 17	2.65	2.28	3.37

Statiscal outcome Specific leaf are (SLA) was determined three times by a destructive harvest. Per destructive harvest three trees were cut. It was tested if the SLA did not differ between the three different moments of destructive harvest. The results of the statistical test are shown in the ANOVA table below.

ANOVA

SLA

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	393.105	2	196.552	.730	.520
Within Groups	1615.881	6	269.314		
Total	2008.986	8			

The K_C value was correlated to LAI, a significant linear relationship was shown. The outcome of the statistical test is shown in the tables below.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.944[a]	.891	.854	.20939	.891	24.440	1	3	.016

a. Predictors: (Constant), LAI

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1.072	1	1.072	24.440	.016[a]
	Residual	.132	3	.044		
	Total	1.203	4			

a. Predictors: (Constant), LAI

b. Dependent Variable: Kc value

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	-.454	.365		-1.245	.302	-1.614	.706
	LAI	.902	.182	.944	4.944	.016	.321	1.482

a. Dependent Variable: Kc value