Differences in hydrological cycles between forests and agricultural land in Europe

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Index

1. Introduction

During the last century, the land cover of Europe rapidly changed from forests to agricultural lands to feed the rapidly growing population (Meeus, 1995; Klein Goldewijk and Ramankutty, 2004). In the first decade of the 21st century this change is reversed and agriculture lands are afforested for conservation of nature and for the storage of greenhouse gasses to counter climate change (Stoate et al., 2009). Another development in Europe is that the increasing demand for biofuels causes extra cultivation of land(Bindraban et al., 2009). A part of this cultivation will likely be accomplished by changing forests into land for biofuels (Warner et al., 2012). In developing countries forests are converted into agriculture lands, because of increase in population and thereby increase of food demand (Balmford et al., 2005; Mandemaker et al., 2011). The increasing demands for food and biofuels, and subsequent change of natural land cover into water demanding agricultural lands increase the demand for water. Scarcity of water is expected to be the key limitation of food production in many countries in Asia and Africa in 2025 (Rijsberman, 2005). Therefore, factors affecting availability of water for biofuels and food production should be known. One of these is the conversion of forests into agriculture because of the demand for biofuels and food. However, the effects of land cover change on the hydrologic cycle are not entirely clear (Vitousek et al., 1997) and are debated (Ellison et al., 2012).

This lack of knowledge about the effects of land cover change on the hydrologic cycle applies for the conversion of agriculture into forests as well. As aforementioned, this conversion is done to counter climate change. However, the effect of land cover change on the hydrologic cycle is not entirely clear and underemphasized in models (Pfister et al., 2004). Conversion of agriculture into forests affects evapotranspiration and consequently climate (Ellison et al., 2012). Besides, it affects the run-off and consequently flood risk (Schilling et al., 2013). Because of these possible negative consequences and the lack of knowledge about the consequences of this land cover change the focus of this research is on the topic of the effects of land cover change between forests and agriculture on the hydrologic cycle. In the next part the important components of the hydrologic cycle are briefly introduced and after that the debate on the effects of the conversion of forests into agriculture and vice versa on the hydrologic cycle is reviewed.

1.1 Components of the hydrologic cycle involved by conversion of land cover

In a very simplified form the hydrologic cycle is as follows: precipitation causes run-off and storage which is sooner or later transferred back into the atmosphere via evapotranspiration. Major components involving change of hydrologic cycle due to conversion of agriculture into forests and vice versa are rooting depth, soil structures, leaf area index, temperature, albedo and stomata conductance (Bonan, 2002). The effect of these components varies for land covers, climate and biotic circumstances, types of land cover (i.e. boreal or broad-leaved forests) and seasonality. This is shown by examples for each of these variations.

Variation in land cover is caused by difference in albedo, root depth, leaf area index and stomata conductance of the vegetation. Deeper roots retain more water and are therefore less vulnerable to droughts (Kleidon and Heimann, 1998). Higher leaf area index induce higher evapotranspiration and a lower albedo (Buermann et al., 2001). Albedo of the surface and vegetation affects temperature by absorption or reflection of heat radiation. Finally, stomata conductance fixes the rate of evapotranspiration of vegetation as higher CO_2 concentration causes lower conductance and thus lower evapotranspiration of vegetation (Lammertsma et al., 2011). *Variation in climate and biotic circumstances* is caused by variation in climate (temperature and precipitation) and soil. Temperature and precipitation are the main drivers of evapotranspiration, thus the climate clearly affects the hydrologic cycle (Dingman, 2002). Depending on structure and roughness of the soil water runs-off or is stored (Lehrsch et al., 1987). *Variation in types of land cover;* coniferous forests and broad-leaved forests have different effects on evapotranspiration (Bosch and Hewlett, 1982) like coniferous forests evaporate less in summer compared to broad-leaved forests (Baldocchi et al., 2008). Difference in structure of vegetation, like rooting depth and stomata conductance, affect the hydrological cycle. *Seasonal variation* influences evapotranspiration because of differences in climate and biotic circumstances. The length of the growing season and length of the snowpack highly influence evapotranspiration rates (Bonan, 2002).

1.2 Debate on the function of land covers in the hydrologic cycle

Knowing these basics of the hydrological cycle and its relation to land covers, the function of land covers in the hydrological cycle is reviewed. In a review of Ellison et al. (2012) mainly the function of forests is debated but it is put against the function of agriculture. According to Ellison et al. (2012) there are two views concerning the function of forests. One view sees forests as a demander. According to this view, forests use water because they evapotranspire water whereby the water is no longer available for other purposes, like agriculture or drinking water, downstream. The other view sees forests as a supplier. In this view, forests enhance the hydrologic cycle by evapotranspiration of water, which subsequently becomes precipitation. While this water is stored, the hydrologic cycle slows down. Therefore evapotranspiration of water is positive, since it redistributes water in the hydrologic cycle. After a review on the debate whether forest should be seen as suppliers or demanders, Ellison et al. (2012) concludes that forests should be seen as suppliers. Their main counterargument against the demander-view is that the evidence is weak in showing that forests decrease the water availability for other ecosystems and economic purposes, since this evidence is only based on small scale studies. Besides, Ellison et al. (2012) emphasize that forests are important in the distribution of moisture and precipitation. Based on this conclusion they argue that conversion of forests into agriculture decreases precipitation. However, the arguing of Ellison et al. (2012) is not entirely solid and therefore three arguments are introduced which question their reasoning.

1) The first argument considers the statement that study cases in small areas do not give good evidence that forests decrease the water availability for other purposes. Study cases in small areas have confirmed the decrease in water availability because of forests (Bosch and Hewlett, 1982; Cao et al., 2008), but in a bigger scale study for entire China, the opposite is found, namely that conversion of pastures to forests increases the water availability (Liu et al., 2008). While these results confirm the statement of Ellison et al. (2012) the same study also showed that the conversion of pastures into forests decreases evapotranspiration. Therefore, this study challenges the reasoning of Ellison et al. (2012) that forests are stronger atmospheric water suppliers than agricultural land. Thus the results of the China study of Liu et al. (2008) criticize the demander and supplier view. So there is confusion concerning the function of forests on a larger scale. Therefore more clarification is needed on the large scale effects of forests on the hydrologic cycle, especially on the water availability and evapotranspiration of forests.

2) The method used by Ellison et al. (2012) does not take any differences in function of forests into account because of differences in climate. This is a major limitation, since climate significantly influence evapotranspiration; evapotranspiration is related to temperature; and precipitation, as oceanic currents, are important transporters of heat and moisture. This is shown also in the global distribution of evapotranspiration as from the equator to the poles evapotranspiration decreases gradually, only disturbed by areas with little precipitation, such as desserts or inland areas, (Dingman, 2002). It is likely that forests in different climates have different functions in the hydrological cycle (Bonan, 2002). Thus the possible differences in function of forests in the hydrological cycle because of differences in climate cannot be neglected in the debate.

3) The third argument against the reasoning of Ellison et al. (2012) counters that forests increase evapotranspiration with respect to other land covers. This argument is consistent with the argument introduced in the first bullet; that forests do not increase evapotranspiration (Liu et al., 2008). This is

found in a research in Sweden (Van der Velde et al., 2013) as well. What is different in the conclusion of Van der Velde et al. (2013) compared to the research of Liu et al. (2008) is that forests do not evapotranspirate more than agriculture, while in the research of Liu et al. (2008) evapotranspiration of forests decreased after afforestation. It also is found in the research of Van der Velde et al. (2013) that in Sweden the conversion from wetlands into forests leads to a higher evapotranspiration, because wetlands have a relative low evapotranspiration. This is contrary to the statement of Ellison et al. (2012) that wetlands or forests are a driver of precipitation because of their high evapotranspiration. However, in summer the evapotranspiration of wetlands is higher than that of boreal forests (Bonan, 2002). Thus seasonality affects evapotranspiration of the land cover as well.

2. Problem definition and research questions

To summarize the above: a lot is unknown about the role of different land covers in the hydrological cycles, especially of forests, and therefore the debate on whether forests are demanders or suppliers cannot be decided yet. However, it is an important debate since the change of land cover from forests to agriculture and vice versa continues, while in the meantime the water demand for human consumption and industries increases as well. Therefore this research aims to investigate whether there is any difference in hydrological cycles between forests and agricultural land cover. The main research question of this thesis is:

What are the differences in hydrological cycles between forests and agricultural land in Europe?

The sub-question are about the difference in effect because of spatial variation, sub-types and seasonal variation:

(1) Are the differences in the hydrological cycles between forests and agricultural land the same for entire Europe or are these differences influenced by climate?
(2) Are there differences in the hydrological cycles between sub-types of forests and agriculture?
(3) Does seasonality affect the hydrological cycle of forests and agriculture?

It is hypothesized for the main question that there are differences between agriculture and forests in hydrologic cycle and mainly because of differences in evapotranspiration.

For the sub-questions is hypothesized that (1) differences between forests and agriculture regarding the hydrological cycle in entire Europe are influenced by the climate, (2) there are differences between sub-types of land cover as they do differ in composition concerning rooting depth and albedo, (3) seasonality affects the hydrological cycles of forests and agriculture as snowpack and grow seasons affect the hydrological cycle.

3. Theoretic background

This chapter introduces the Budyko framework that will be used to identify differences between agriculture and forests in the hydrological cycles. At first, evapotranspiration is defined. Because evapotranspiration is one of the most important elements of the Budyko framework and, based on the review of the hydrological cycle in relation to land covers in chapter one, evapotranspiration is the key factor in possible differences between agriculture and forests regarding the hydrological cycle. In the same paragraph the Budyko framework itself is introduced (paragraph 3.1). This is followed by a paragraph (3.2) about applications of the Budyko framework and in paragraph 3.3 the way of calculation of actual and potential evapotranspiration is explained.

3.1 The Budyko framework

Because evapotranspiration is the key process in this research a definition is important. The definition for evapotranspiration is taken from Dingman (2002, p.272):

'Evapotranspiration is a collective term for all the processes by which water in the liquid or solid phase at or near the earth's land surfaces becomes atmospheric water vapour'

The definition shows the two main drivers of evapotranspiration; water and energy. Water is needed as the input of evapotranspiration and energy is needed to bring the water from solid or liquid to vapour. Based on these two main drivers Budyko (1974) made a framework to classify areas of vegetation on a global scale. Budyko (1974) combined radiation balance, air temperature and atmospheric humidity in a simplified heat balance (equation 1.1) and a water balance (equation 1.2) for land surfaces into one equation (1.3).

$$\frac{R}{Lr} = \frac{E}{P} + \frac{H}{\lambda_P} \qquad \text{[equation 1.1]}$$

$$1 = \frac{E}{P} + \frac{f}{P} \qquad \text{[equation 1.2]}$$

$$\frac{E}{P} = \Phi\left(\frac{R}{\lambda_P}\right) \qquad \text{[equation 1.3]}$$

R stands in these equations for radiation (W/m^2), λ_P for latent heat of vaporization of precipitation (W/m^2), E for evapotranspiration (mm yr^{-1}), H for sensible heat flux, P for precipitation (mm yr^{-1}), f for run-off (mm yr^{-1}), Lr for latent heat of precipitation (W/m^2), and Φ stands for a determined coefficient (no dimension).

Equation 1.3 is known as the dryness index. In simplified form the dryness index is R/λ_P, this equals E_0/P, with E_0 as potential evapotranspiration. Since the dryness index is derived from the heat and water balance the output of the dryness index reveals whether a catchment or area tends to be energy limited (E_0) or water limited (P). A catchment or area is energy limited in case E_0 is much bigger than P (either $R >> \lambda_P$) and it is water limited when P approaches E_0 (either $R << \lambda_P$).

To explain the relationships between evapotranspiration, precipitation and potential evapotranspiration even further Zhang's model is used (Zhang et al., 2001).
This model, however, uses temperature instead of potential evapotranspiration to describe the energy factor the approach of Zhang's model is based on Budyko's framework. The model of Zhang et al. (2001) shows that when temperature (or energy) increases, precipitation and evapotranspiration increase. But precipitation increases relatively faster than evapotranspiration. This leads to a logarithmic relationship between precipitation and evapotranspiration (Zhang et al., 2001). Based on this relationship it can be derived that the relative amount of precipitation converted into evapotranspiration is higher in areas with a wet climate than areas with a dry climate. Secondly, Zhang's model shows that with an increase in temperature the logarithmic relationship between precipitation and evapotranspiration less suddenly tends to a smooth constant line. Thus, areas with lower temperatures reach, by a lower amount of precipitation, earlier the (almost) maximum evapotranspiration than areas with a higher temperature. Abovementioned reasoning shows that land cover types are limited to a defined relative amount of evapotranspiration dependent on the input of water (precipitation) and energy (temperature or potential evapotranspiration).

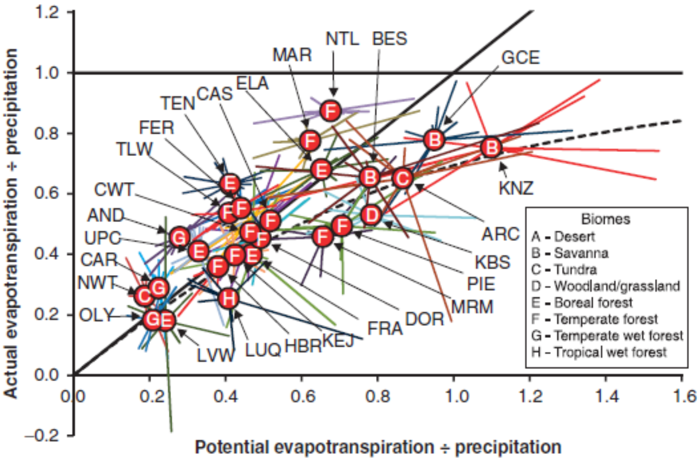

Figure 1. Variation in ranges of dryness index and evaporative index of different biomes in the United States (Jones et al., 2012).

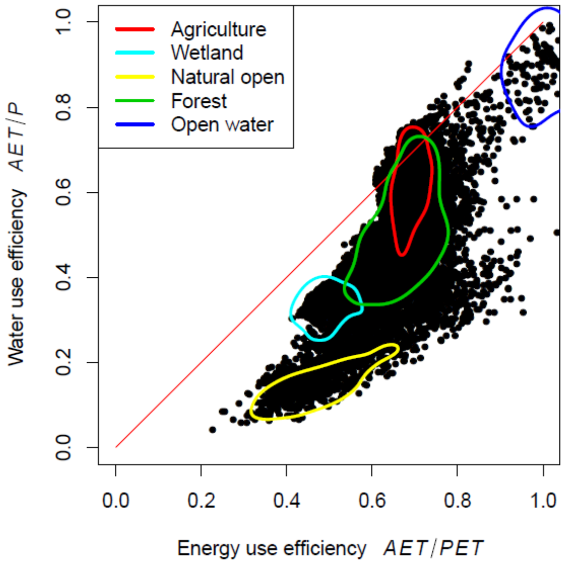

Figure 2. Water and energy use efficiency of different land covers in Sweden (Van der Velde et al., 2013).

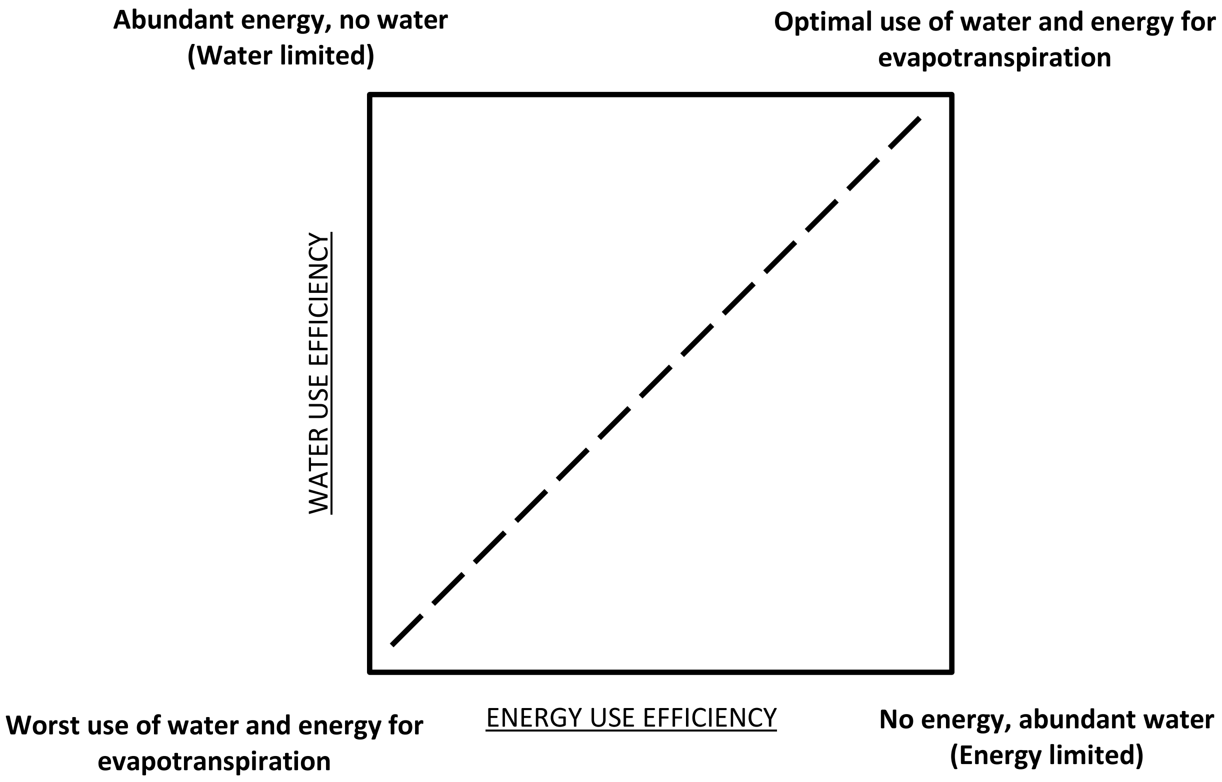

Figure 3. Explanation of the Budyko framework as applied in a graph by Van der Velde et al. (2013). Land covers in on the left side of the diagonal tend to be water limited, when land covers are on the right side they tend to be energy limited. Furthermore, following the line from the left down corner to the upper right corner of the graph the better water and energy are used for evapotranspiration.

3.2 Applications of the Budyko framework

In applications of the Budyko framework it is shown that land cover types are indeed limited to water and energy. With the aforementioned dryness index a map can be created with classifications of geobotanic zones which correspond with the actual geobotanic zones (Budyko, 1974). The same approach was also used in combination with climate models to estimate the consequences of climate change for the division of geobotanic zones (Monserud et al., 1993). Another way of classification is by the evaporative index of Budyko (1974). The evaporative index is calculated by dividing actual evapotranspiration by precipitation. Another use of the evaporative index is as indication of the efficiency of vegetation in use of water (Granger, 1989).

When values of the dryness index are put against the evaporative index a graph, the so-called Budyko analysis, is performed (Budyko, 1974). An example of this can be found in figure 1, a graph of Jones et al. (2012). It shows that biomes have a limited variation in dryness index and evaporative index. Van der Velde et al. (2013) shows the same for land cover types in Sweden, where they found that different types of land cover are within certain ranges of the evaporative index , see figure 2. However, Van der Velde et al. (2013) does compare the evaporative index, named water use efficiency by Van der Velde et al. (2013), with energy use efficiency and not with the dryness index. The term energy use efficiency is calculated by dividing actual evapotranspiration by potential evapotranspiration (Van der Velde et al., 2013). Thus energy use efficiency shows how much of the potential evapotranspiration, which equals the evapotranspiration when energy is fully used for conversion of liquid or solid water to vapour, is actually evaporated. Water use efficiency, on the other hand, shows how much of the precipitation is transferred into vapour. Values of both water and energy use efficiency are theoretically between zero and one, because it is not possible to have a higher actual evapotranspiration than in potential is plausible. Also it is theoretically not plausible that more water is evaporated than falls as precipitation. Surface or groundwater flow into the area of research can cause values higher than one, as this flow is not taken into account as precipitation. The application of the Budyko framework of Van der Velde et al. (2013) is useful to clarify whether types of land cover are water or energy limited and whether they use water and energy efficient or not. In figure 3 is shown how to read the graph of Van der Velde et al. (2013). The combination of efficiency and limitation in water and energy ensures that the most important components the hydrological cycle are taken into account. Therefore the graph of Van der Velde et al. (2013) is applied in this research to discover whether forests and agriculture are different in the hydrological cycle.

3.3 Calculation of actual and potential evapotranspiration

It is important to notice that the way of calculating actual evapotranspiration and potential evapotranspiration influences the results of water and energy use efficiency. Inclusion or exclusion of components like soil moister, interception of precipitation and sublimation can cause different results of water and energy use efficiency. Therefore, the next paragraph describes the calculation of actual and potential evapotranspiration.

The most simple approach to calculate *actual evapotranspiration* is by the water balance: $E = Q - P - \Delta S$. Where Q is the discharge and ΔS the change in storage. The restrictions of this approach are that the area of interest has to be gauged and the change of storage has to be known, which is difficult since storage of water in soil and vegetation is hard to estimate. Therefore another approach is to calculate evaporation based on the heat balance (Dingman, 2001, p. 274):

$$LE = K + L - G - H + A_w - \frac{\Delta Q}{\Delta t} \qquad \text{[equation 2]}$$

In this equation LE is the latent heat (or evaporation) (W/m^2), K is the net shortwave radiation input (W/m^2), L is the net longwave radiation input (W/m^2), G is net output of radiation to the ground

(W/m^2), H is output of sensible-heat to the atmosphere (W/m^2), A_w is the net water-advected energy(W/m^2), ΔQ is the change of heat stored (W/m^2) divided by the change of time (yr^{-1}).

Dividing equation 2 by ‘$\rho_w \cdot \lambda_v$’, the density of water times the latent heat of vaporization, results in the rate of evaporation (Dingman, 2002, p.281). This equation was combined by Penman (1948) with the principle of mass-transfer, which is founded on the Dalton-type equations. It is assumed that there is no storage of energy, negligible conduction of heat to the ground and negligible net water-advected energy. Furthermore H is rewritten in other variables. These derivation can be found in Dingman (2002, box 7-1) and results in:

$$E = \frac{\Delta \cdot (K+L) + \gamma \cdot K_e \cdot \rho_w \cdot \lambda_v \cdot v_a \cdot e_a^* \cdot (1 - W_a)}{\rho_w \cdot \lambda_v \cdot (\Delta + \gamma)} \qquad \text{[equation 3]}$$

Υ is the psychrometric constant (Pa K^{-1}), K_e is a coefficient of the efficiency of vertical transport of water vapour by turbulent eddies of wind (m s^2 kg^{-1}), v_a is the wind speed (m s^{-1}) , e_a^* is the saturation vapour pressure of the air temperature (Pa), W_a is the relative humidity (-).

Equation 3 was further extended by Monteith (1965), who included transpiration of vegetation in the calculation of evapotranspiration.

$$E = \frac{\Delta \cdot (K+L) + \rho_a \cdot c_a \cdot C_{at} \cdot e_a^* \cdot (1 - W_a)}{\rho_w \cdot \lambda_v \cdot [\Delta + \gamma \cdot \left(1 + {}^{C_{at}}/_{C_{can}}\right)]} \qquad \text{[equation 4)}$$

Here, ρ_a is the air density (kg m^{-3}), c_a is the heat capacity of air (J kg^{-1} K^{-1}), C_{at} is the atmospheric conductance of water vapour (m s^{-1}) and C_{an} is the canopy conductance (m s^{-1}).

To calculate evapotranspiration the input has to be accurate. Cleugh et al. (2007) modified the Penman-Monteith equation to make it applicable for remotely sensed data. The biggest modification is the incorporation of surface resistance which is linearly related to the leaf area index, which is measured by MODerate Resolution Imaging Spectroradiometer (MODIS) at satellites. Mu et al. (2007) improved the equation of Cleugh et al. (2007) by several changes in how to incorporate vegetation in the calculation of evapotranspiration and to include soil evapotranspiration, which was neglected before. This calculation is improved by Mu et al. (2011) by including evapotranspiration by night. Generalized actual evapotranspiration is calculated as the sum of evapotranspiration of wet canopy surface, plant transpiration and evapotranspiration from soil surface. The results of the calculations have a correlation coefficient of 0.86 compared to measurements (Mu et al., 2011). The Modis derived evapotranpiration by Mu et al (2011) will be used in this thesis.

Potential evapotranspiration is the maximum of evapotranspiration possible when there is no water limitations. In MODIS potential evapotranspiration is calculated by the sum of evapotranspiration from wet canopy surface, potential plant transpiration, evapotranspiration from wet soil surface and potential evapotranspiration from soil surface (Mu et al., 2011).

4. Data

To study the differences in energy use efficiency and water use efficiency of forests and agriculture, areas with this land cover are selected. Open areas and sparse vegetated areas are selected too, for these areas are used as reference point, which is explained later on. With this selection three datasets are created: one dataset with yearly data, one dataset with seasonal data and one dataset with yearly data of more specific land uses . Table 1 summarizes the different datasets and the inputs of the datasets.

Values of potential and actual evapotranspiration are obtained from MODIS (Mu et al., 2011). Values of precipitation are taken from e-obs dataset (Haylock et al., 2008). For MODIS as well as e-obs data is taken for the years 2000 to 2012.

What? **(Source)**	**MODIS** **(NASA)**	**E-OBS** **(ECA-D)**	**CLC2006** **(EEA)**	**MNVE** **(Bohn et al.)**
Used data	Actual and potential evapotranspiration	Precipitation	Land Use Cover	Natural Vegetation
Time period	2000-2012	2000-2012	2006	NA
Time scale	Yearly or monthly	Daily	NA	NA
Dataset 1: Yearly	Average per year	Average per year	Forests, agricultural & open and sparse vegetated areas	Zones of natural vegetation: D, F, G and J
Dataset 2: Seasonally	Average per season	Average per season	Forests, agricultural & open and sparse vegetated areas	Zones of natural vegetation: D, F, G and J
Dataset 3: Specific Land Covers	Average per year	Average per year	3 types of forest areas 4 types of agricultural areas 2 types of open and sparse vegetated areas	Zones of natural vegetation: D, F, G and J

Table 1. Summary of the used input data for each dataset. The types of specific land covers and zones of natural vegetation are explained in the text.

The Corine Land Cover 2006 or CLC2006 (EEA, 2013) is used as a map for the land use. This map is organized at three levels of detail, in which the first level contains six classes, the second level fifteen classes and the third level forty-four classes. In this research forests refer to the second level class ‘forests’ in the CLC2006, agriculture refers to the first level class ‘agricultural areas’, open and sparse vegetated areas refer to the first level class ‘forest and semi natural areas’, excluding the second level classes ‘forests’ and the third level class ‘glaciers and perpetual snow’. Furthermore, the types of specific land uses, which are used in dataset 3, are for agriculture the second level classes ‘arable land’, permanent crops’, ‘pastures’ and ‘heterogeneous agricultural areas’, for forest the third level classes ‘broad-leaved forest’, ‘coniferous forest’ and ‘mixed forest’, and for open and sparse vegetated areas the second level classes ‘scrub and/or herbaceous vegetation associations’ and ‘open spaces with little or no vegetation’, without the third level class ‘glaciers and perpetual snow’.

5. Data analysis

5.1 Establishment of the three datasets

For the Budyko analysis energy use efficiency and water use efficiency are calculated for areas with a unique land use type. Each area has a surface equal or larger than 100 km^2 and smaller than 10 000 km^2. The minimum surface of 100 km^2 is set to avoid influences of adjacent areas with a different land cover. Furthermore, the minimum is based on the resolutions of the input data, which is for MODIS 1 km, for precipitation 0.25 degrees (approximately 28 km) and for CLC2006 0.25 km. Because the classes of the CLC2006 do not match the classes in this study, adjacent areas with the same class according to this study, but not according to the CLC2006, are dissolved into one area. Hereafter the surface areas are calculated. Areas smaller than 100 km^2 are removed from the dataset and areas larger than 10 000 km^2 are manually split in smaller areas. This results in a dataset with numerous individual areas for each land use with a surface between the 100 km^2 and 10 000 km^2. It was chosen to split areas larger than 10 000 km^2, because all areas in the Budyko framework are treated as equally sized and otherwise the range of sizes would become too large.

For each individual area the values of potential evapotranspiration, actual evapotranspiration and precipitation are taken from the inputs. For datasets 1 and 3 the values are a yearly average. The data of MODIS taken in this case are on a yearly scale and are averaged per individual area over the used time scale (2000 to 2012). The e-obs data are on a daily scale and are therefore firstly summed per year to a yearly value per individual area and then averaged over the used time scale. The same procedure is applied to monthly dataset 2, with the only exception that the MODIS data is taken per month and summed to a seasonal value and the precipitation per year is summed to a seasonal value too. Afterwards these values are averaged for each season. With these data the energy use efficiency and water use efficiency are calculated per individual area and per dataset.

5.2 Classification of climate zones

The difference between land cover type due to biotic factors (occurrence and kind of plants), the map of natural vegetation of Europe (Bohn et al., 2000/2003) is used as reference. This map classifies where vegetation would occur when there is no anthropogenic interference, so called potential natural vegetation, on the basis of ecological, climatological and geological circumstances (Bohn, 1995). It is used in this research since it levels out the effects of climatic factors (amount of water and energy) and geological factors (roughness and soil texture). The map compromises different maps of potential natural vegetation in Europe which favours the use of this map over other maps of potential natural vegetation.

Four zones of natural vegetation of the map of Bohn et al. (2000/2003) are selected, because it appears with an overlay of the map of the CLC2006 that these four zones contain sufficient big forests and agricultural areas to conduct a proper comparison. Besides, these four zones cover most aof Europe, as can be seen in figure 4. The zones of natural vegetation are 'mesophytic and hygromesophytic coniferous and mixed broad-leaved-coniferous' (classified as 'D'), 'Mesophytic deciduous broad-leaved and mixed coniferous-broad-leaved forests' (classified as 'F'), 'Mediterranean sclerophyllous forests and scrub' (classified as 'J') and 'Thermophile mixed deciduous broad-leaved forests' (classified as 'G'). The classifications are adopted from Bohn et al. (2000/2003) and the appearance of the zones of natural vegetation are mapped in figure 4. Areas which are, due to this selection, not taken into account are steppes, desserts, alpine areas, arctic areas and water related areas.

5.3 Comparison to open and sparse vegetated areas

An extra comparison is done between forest and agriculture with areas that are open and sparse vegetated. The aim of this comparison is to find out if vegetation affects water and energy use efficiency. Because open and sparse vegetated areas are almost not vegetated these areas show the effect of vegetation on water and energy use efficiency when these areas are compared to agricultural areas and forests.

5.4 Analysis of the three datasets

All datasets are tested to see whether they are normally distributed. Hence an E-statistic test of multivariate normality (Székely and Rizzo, 2005) is used, considering that the data are bivariate. The Budyko analysis is bivariate owing to the fact that energy use efficiency and water use efficiency are compared against each other. Most of the datasets are found to be non-normally distributed, even after transformation of data. Since most of the data are non-normally distributed, is bivariate and all the data have to be comparable, almost none of the statistic tests are applicable. For example, because the Budyko analysis is bivariate the Mann-Whitney U test cannot be used for the comparison of means between two groups, like forests and agriculture, as this test only applies to univariate data. There is no applicable test found to test whether the groups are significantly different. Subsequently, to show differences between groups bagplots are used. Bagplots are boxplots for non-normal distributed bivariate data (Rousseeuw et al., 1999). A bagplot contains an inner area, the baghull, and an outer area, the loophull. The baghull contains fifty per cent of the values,

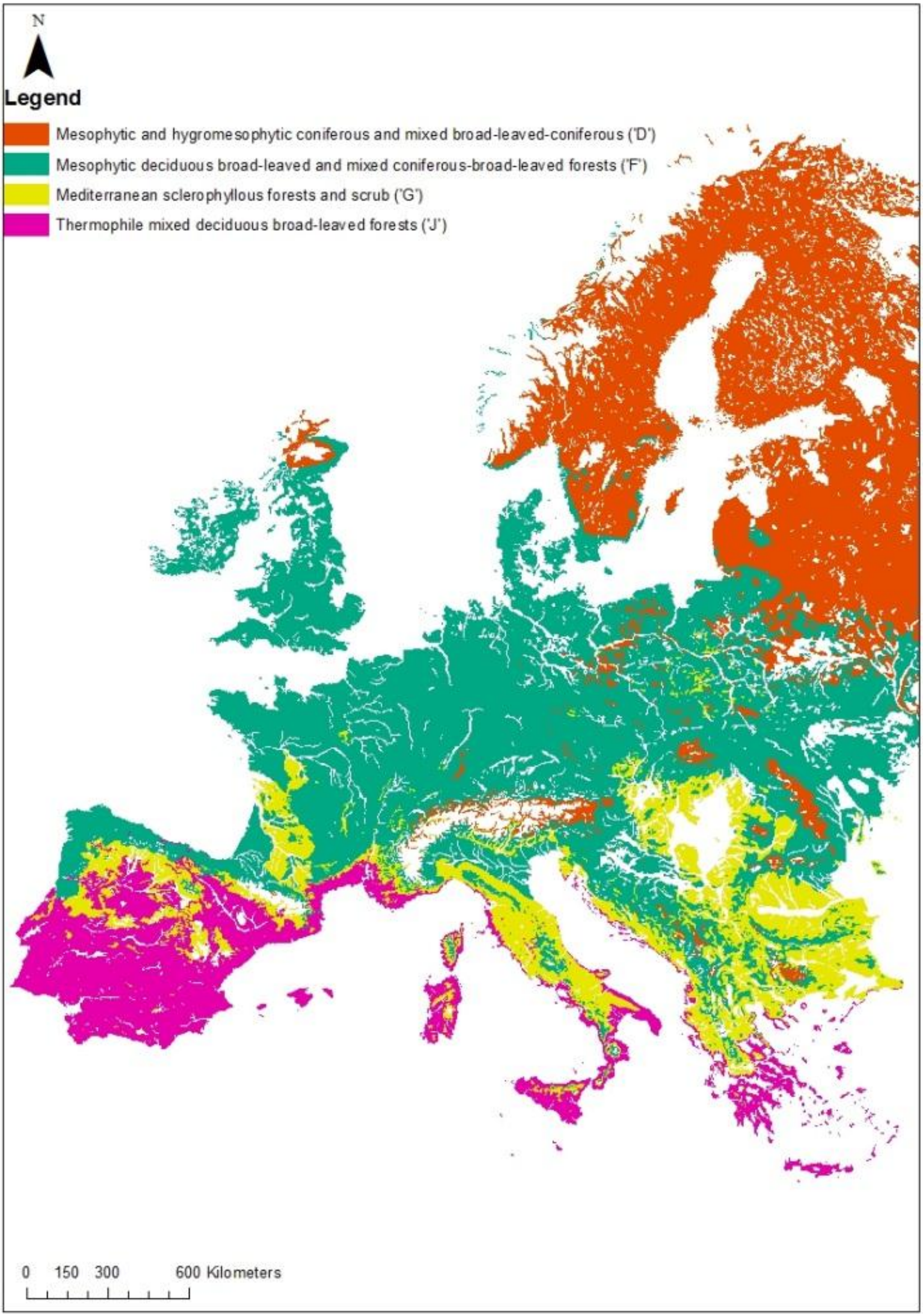

Figure 4. Map of selected zones of natural vegetation in Europe. Based on Bohn et al. (2000/2003).

the loophull contains the remaining values except for the outliers. The outliers lay outside the loophull.

The components of the Budyko analysis, water and energy use efficiency, apart are univariate. Therefore, for each of those components a Mann-Whitney U test can be applied. A Kruskal-Wallis test can be applied likewise, as it compares univariate data for more than 2 groups on significant difference, but this test does not show which groups differ from each other. This can be done by a Mann-Whitney U test that only compares two groups. Since this study is focused mainly on two groups, agriculture and forests, a Mann-Whitney U tests is performed. Another point of attention should be the number of outliers in the data. These make the mean less reliable as an estimator of the real mean. Hence the median is taken as estimator of the real mean.

6. Results

This chapter starts in paragraph 6.1 with comparing water and energy use efficiencies for the three land cover types for entire Europe to identify differences in water and energy use efficiency between forests, agriculture and open and sparse vegetated areas. In the second paragraph, the same comparison is performed for each zone of natural vegetation. This comparison is done twice to identify differences in water and energy use efficiencies between the three land covers within each natural vegetation zone and between the four natural vegetation zones for each land cover type (paragraph 6.2). Thirdly, for each land cover a comparison is performed between the subtypes of each land cover. This comparison is performed within each zone of natural vegetation (paragraph 6.3). Fourthly, the values of water and energy use efficiency of the three land covers are compared within and between the different seasons in the different zones of natural vegetation (paragraph 6.4). Finally, the main results of the different paragraphs are summarized and the differences and similarities of these main results are pointed out (paragraph 6.5).

6.1.1 Water and energy use efficiency of the three land covers in entire Europe

The hypothesis, that agriculture and forests differ either in water use efficiency or energy use efficiency for entire Europe, is confirmed by a Mann-Whitney U test. This test shows that there is a significant difference in energy use efficiency between forests and agriculture in Europe, because the p-value of 0.01 is smaller than the 0.05 (see table 1) and that there is no significant difference in water use efficiency, because the p-value is 0.36 and thus is larger than 0.05 (see table 1). Besides, forests have a higher energy use efficiency than agriculture, as shown by the medians in figure 5. The bagplots in figure 5 show that agriculture has a bigger range in energy use efficiency than forests and that the median of agriculture is slightly lower than the median of forests. For water use efficiency the difference in range between forests and agriculture is even smaller compared to the difference in energy use efficiency. Thus, the bagplots show that the differences in water and energy use efficiency are small, but that the difference in energy use efficiency is slightly larger than the difference in water use efficiency and is significant, as the Mann-Withney U test showed.

	Energy Use efficiency (p-value)	**Water Use efficiency (p-value)**	**Actual evapotranspiration (p-value)**	**Potential evapotranspiration (p-value)**	**Precipitation (p-value)**
Agc and Frs	**0.01**	*0.36*	**0.00**	**0.00**	*0.27*
Agc and O&S	**0.00**	**0.00**	**0.02**	**0.00**	*0.13*
Frs and O&S	**0.00**	**0.00**	**0.00**	**0.00**	*0.46*

Table 1. The table shows the results of the Mann-Withney U test ($p<0.05$) between two types of land cover and for different variables. Values that are bold show significant values. Agriculture is abbreviated to Agc, forests to Frs and open and sparse vegetated areas to O&S.

The next question is why forests and agriculture differ significantly in energy use efficiency. Comparison of the bagplots of forests and agriculture with the bagplots of open and sparse vegetated areas(see figure 5) show that values of open and sparse vegetated areas for water and energy use efficiency are clearly lower than the values of agriculture and forests for water and energy use efficiency. The Mann-Whitney U test demonstrates that the differences of both water and energy use efficiency are significant between forests and open and sparse vegetated areas as well as between agriculture and open and sparse vegetated areas. Thus difference in vegetation can explain significant difference in water and energy use efficiency between land covers and could also explain the significant differences between agriculture and forests. However, the difference between agriculture and forests is only significant for energy use efficiency and not for water use efficiency.

6.1.2 Explanation of results for Europe

That the difference in energy use efficiency is significant between forests and agriculture but is not significant for water use efficiency is explained by the difference in calculation of water and energy use efficiency. As figure 6 shows, the means and distributions of actual and potential evapotranspiration between the three land covers differ, while the means and distributions of precipitation are similar. A Mann-Withney U-test confirms that the difference between forests and agriculture of actual and potential evapotranspiration are significant, whereas the difference in precipitation is not significant between forests and agriculture. As the calculations of water and energy use efficiency differ in respectively the input of precipitation and the input of potential evapotranspiration. Accordingly, it is logical that the energy use efficiency differs more between the types of land cover than water use efficiency, because potential evapotranspiration differs significantly between forests and agriculture and precipitation does not. This is even more highlighted by the fact that open and sparse vegetated areas do differ significantly in potential and actual evapotranspiration when compared to agriculture and forest but do not differ significantly for precipitation compared to agriculture and forests.

6.2.1 Difference between water and energy use efficiency of the three types of land cover in the zones of natural vegetation

However, the distribution of the areas of the three land covers are not equal among Europe, as shown in table 2. The differences in water and energy use efficiencies could also be due to the difference of distribution of the three land covers across Europe. To exclude the difference in distribution the three land covers are compared in zones of natural vegetation.

	D	F	G	J	Total		D	F	G	J	Total
Arable lands	25 7%	213 64%	66 20%	30 9%	**334** **63%**	**Agriculture**	41 16%	131 52%	44 18%	34 14%	**250** **32%**
Permanent crops	~~0~~ ~~0%~~	~~6~~ ~~22%~~	~~7~~ ~~26%~~	14 52%	**27** **5%**						
Pastures	~~1~~ ~~2%~~	49 84%	~~5~~ ~~9%~~	~~3~~ ~~5%~~	**58** **11%**						
Heterogeneous areas	~~7~~ ~~7%~~	42 40%	26 25%	29 29%	**104** **20%**						
Broad-leaved forests	~~10~~ ~~5%~~	115 58%	51 26%	23 12%	**199** **52%**	**Forests**	55 14%	242 60%	70 17%	37 9%	**404** **52%**
Coniferous forests	52 28%	116 62%	~~9~~ ~~5%~~	~~10~~ ~~5%~~	**187** **48%**						
Open spaces	~~7~~ ~~23%~~	12 40%	~~8~~ ~~27%~~	~~3~~ ~~10%~~	**30** **22%**	**Open and sparse vegetated areas**	~~10~~ ~~8%~~	52 40%	34 26%	34 26%	**130** **17%**
Sparse vegetated areas	~~7~~ ~~7%~~	42 39%	30 28%	28 26%	**107** **78%**						

Table 2. Number of areas of (sub-types of) land covers selected in zones of natural vegetation and in Europe. The percentages show what their relative contribution is to the total of a sub-type (like arable lands), or land cover (like agriculture) or total of land cover. Numbers which are lined through are concerned to be not representative. To be representative a land cover has to consist at least 20 individual areas or present more than 40% of the type of land cover.

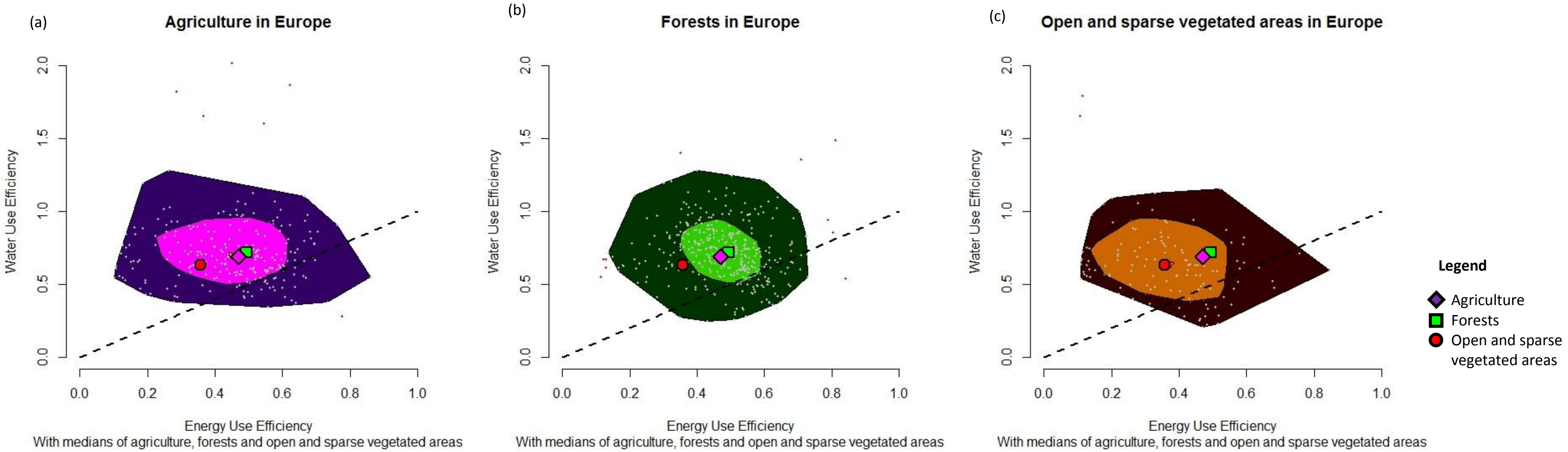

Figure 5. Bagplots and medians of water and energy use efficiency of agriculture (a), forests (b) and open and sparse vegetated areas (c) in Europe. The individual values inside the loophull are grey and outliers outside the loophull are red.

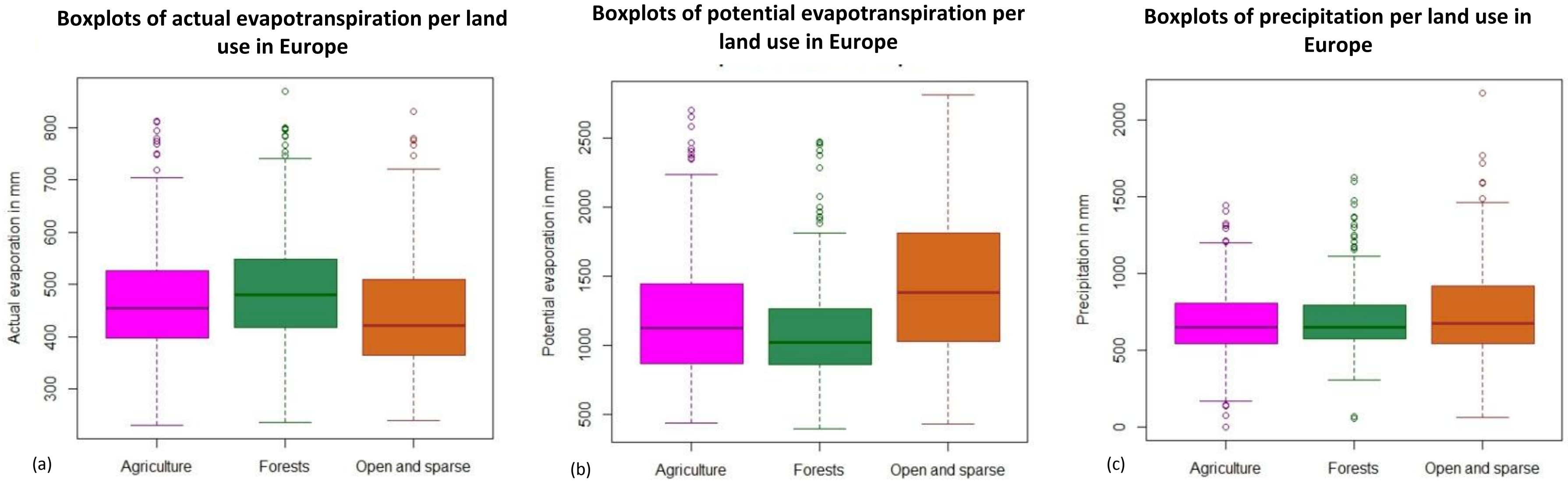

Figure 6. Boxplots of actual evapotranspiration (a), potential evapotranspiration (b) and precipitation (c) for each of the three types of land cover.

A Mann-Whitney U test shows that for each land cover between the four zones there is significant difference in energy use efficiency. Figure 7 shows that land covers in zone 'J' have the lowest energy use efficiency, followed by zone 'G' and zone 'F'. Zone 'D' has the highest energy use efficiency. Thus, energy use efficiency increases when there is less available energy. Surely, zone 'D' is the most northern area, followed by zone 'F', zone 'G' and finally zone 'J'. For water use efficiency there are less significant differences between zones of natural vegetation. For agriculture only zone 'G' is significantly different to all other zones of natural vegetation. For forests significant difference is found between all zones of natural vegetation, excepted between 'J' and 'F'. For open and sparse vegetated areas no significant differences in water use efficiency are found between the areas of natural vegetation. So in general the difference between zones of natural vegetation for energy use efficiency is significant for the three land covers, while the difference between zones of natural vegetation is sometimes significant for water use efficiency. This implies that it is possible that the significant difference in energy use efficiency seen between forests and agriculture in entire Europe is due to difference in distribution. Considering that both differences between natural zones of vegetation and differences between agriculture and forests in entire Europe are significant for energy use efficiency.

Agc	D	F	G
F	*0.2691*		
G	**0.0000**	**0.0000**	
J	*0.8984*	*0.3636*	**0.0000**
Frs	D	F	G
F	**0.0001**		
G	**0.0000**	**0.0000**	
J	**0.0065**	*0.9782*	**0.0016**
O&S	D	F	G
F	NR		
G	NR	*0.0924*	
J	NR	*0.8563*	*0.0577*

Agc	F	G	J
D	**0.0001**	**0.0000**	**0.0000**
F		**0.0000**	**0.0000**
G			**0.0189**
Frs	F	G	J
D	**0.0000**	**0.0000**	**0.0000**
F		**0.0000**	**0.0000**
G			**0.0015**
O&S	F	G	J
D	NR	NR	NR
F		**0.0322**	**0.0000**
G			**0.0042**

Table 3. Values of Mann-Withney U test (p<0.05) of comparison of zones of natural vegetation within the types of land cover. The right table are the comparisons for the energy use efficiency while the left table contains the values of the tests for water use efficiency. Values that are bold show significant values. Agriculture is abbreviated to Agc, forests to Frs and open and sparse vegetated areas to O&S. NR means not representative and is based on table 2.

Energy use efficiency	D	F	G	J
Agc and Frs	*0.8998*	*0.5298*	**0.0008**	*0.2444*
Agc and O&S	NR	**0.0005**	*0.7371*	*0.3829*
Frs and O&S	NR	**0.0000**	**0.0021**	**0.0269**
Water use efficiency	**D**	**F**	**G**	**J**
Agc and Frs	*0.1289*	*0.2802*	*0.3971*	*0.2218*
Agc and O&S	NR	*0.0526*	**0.0040**	*0.3379*
Frs and O&S	NR	**0.0059**	**0.0009**	**0.0312**

Table 4. Mann-Whitney U test (p<0.05) between types of land cover within zones of natural vegetation. Values that are bold show significant values. Agriculture is abbreviated to Agc, forests to Frs and open and sparse vegetated areas to O&S. NR means not representative and is based on table 2.

6.2.2 Differences in water and energy use efficiency within zones of natural vegetation

To research whether the differences in the Budyko analysis between forests and agriculture for entire Europe occur because of difference in distribution in the zones of natural vegetation or because of difference in land cover the three land covers are compared within each zone of natural vegetation. Results show that agriculture and forests do not differ significantly for water use efficiency in all zones of natural vegetation (see table 4). For energy use efficiency only zone 'G' shows a significant difference between agriculture and forests. Thus when forests and agriculture are compared within equal climate and biotic circumstances no significant difference is found in water use efficiency and for energy use efficiency only significant difference is found in one zone of natural vegetation.

When looking at the difference between forests and open and sparse vegetated areas for each zone, the results show that for energy use efficiency as well as for water use efficiency in all representative zones of natural vegetation there is a significant difference between forests and open and sparse vegetated areas. The difference between agriculture and open and sparse vegetated areas in water use efficiency is only significant in zone ‘G’. For energy use efficiency agriculture and open and sparse vegetated areas only differ significantly in zone ‘F’. As a result, as figure 7 shows, forests have a significant higher water and energy use efficiency than open and sparse vegetated areas, while agriculture and open and sparse vegetated areas differ significant hardly. Besides, it is remarkable that for entire Europe only significant differences are seen between open and sparse vegetated areas and forests and agriculture in water and energy use efficiency, whereas by comparison in equal climate and biotic circumstances there are less significant differences. Hence, climatic and biotic circumstances are important factors which highly influence water and energy use efficiency.

6.3 Energy and water use efficiency between sub-types of each land cover

In some zones it is found that agriculture and open and sparse vegetated areas differ significantly for either water or energy use efficiency. This is possible due to differences of distribution of sub-types of forests and agriculture in the different zones of natural vegetation. For example, as table 2 shows, permanent crops only occur in zone ‘J’ and pastures only occur in zone ‘F’. Also, for forests and open and sparse vegetated areas there are differences between the zones of natural vegetation in composition of sub-types. To see whether this affects water and energy use efficiency for each land cover the sub-types are compared to each other in the different zones of natural vegetation.

6.3.1 Energy and water use efficiency between sub-types of agriculture

Firstly, sub-types of agriculture are compared in the different zones of natural vegetation. As table 5 shows, in zone ‘F’ the difference in energy use efficiency between heterogeneous areas, arable lands and pastures, are significant. Here the heterogeneous areas have the highest energy use efficiency followed by arable lands and pastures. The only significant difference in zone ‘F’ for water use efficiency is that pastures have a significant higher water use efficiency than arable lands. In zone ‘G’, the two representative sub-types, heterogeneous areas and arable lands differ significantly in energy use efficiency also but do not differ significantly in water use efficiency. Again heterogeneous areas have a significantly higher energy use efficiency than arable lands. In zone ‘J’ heterogeneous areas and arable lands do not differ significantly in energy use efficiency nor in water use efficiency. The only significant difference found in zone ‘J’ is that arable lands have a significant higher water use efficiency than permanent crops. Why some sub-types sometimes do differ significant depends probably on factors like growing season and rooting depth.

Sub-types of agriculture (water use efficiency)		
Zone F	Arable lands	Pastures
Pastures	**0.0084**	x
Heterogeneous areas	*0.1650*	*0.7185*
Zone G	Arable lands	Heterogeneous areas
Heterogeneous areas	*0.9965*	x
Zone J	Arable lands	Permanent crops
Permanent crops	**0.0365**	*x*
Heterogeneous areas	*0.2072*	*0.3100*

Sub-types of agriculture (energy use efficiency)		
Zone F	Pastures	Heterogeneous areas
Arable lands	**0.0000**	**0.0365**
Pastures	x	**0.0000**
Zone G	Heterogeneous areas	
Arable lands	**0.0136**	
Zone J	Permanent crops	Heterogeneous areas
Arable lands	*0.4174*	*0.5930*
Permanent crops	*x*	*0.7489*

Sub-types of forests	
Zone F	Broad-leaved versus coniferous forests
Broad-leaved forests	**0.0163**
Coniferous forests	**0.0000**

Sub-types of open and sparse vegetated areas	
Zone F	Open spaces verus sparse vegetated areas
Water use efficiency	*0.0683*
Energy use efficiency	*0.8936*

Table 5. Mann-Withney U test (p<0.05) for types of land cover in different zones of natural vegetation. Values that are bold show significant values. Not representative areas are excluded based on table 2.

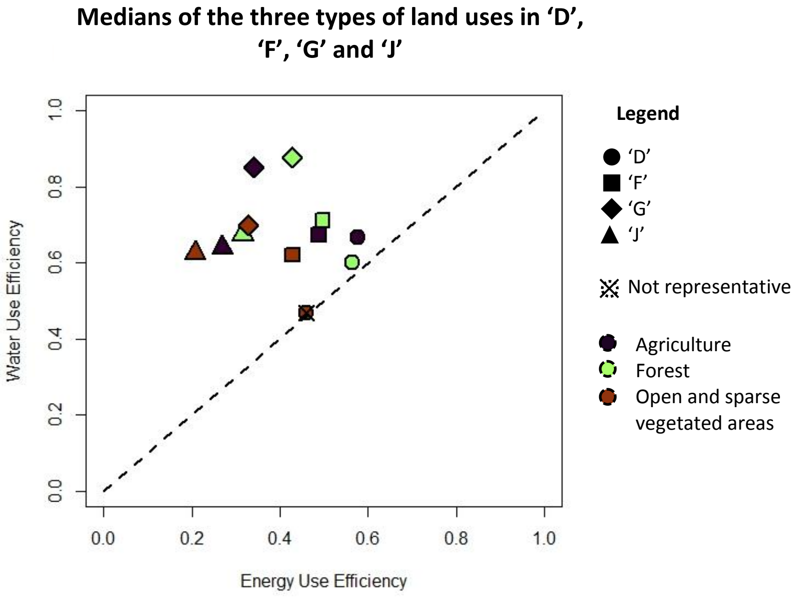

Figure 7. Water and energy use efficiency of agriculture, forests and open and sparse vegetated areas in zones of natural vegetation. Values which are based on to less individual areas are marked with a cross, see table 2 also.

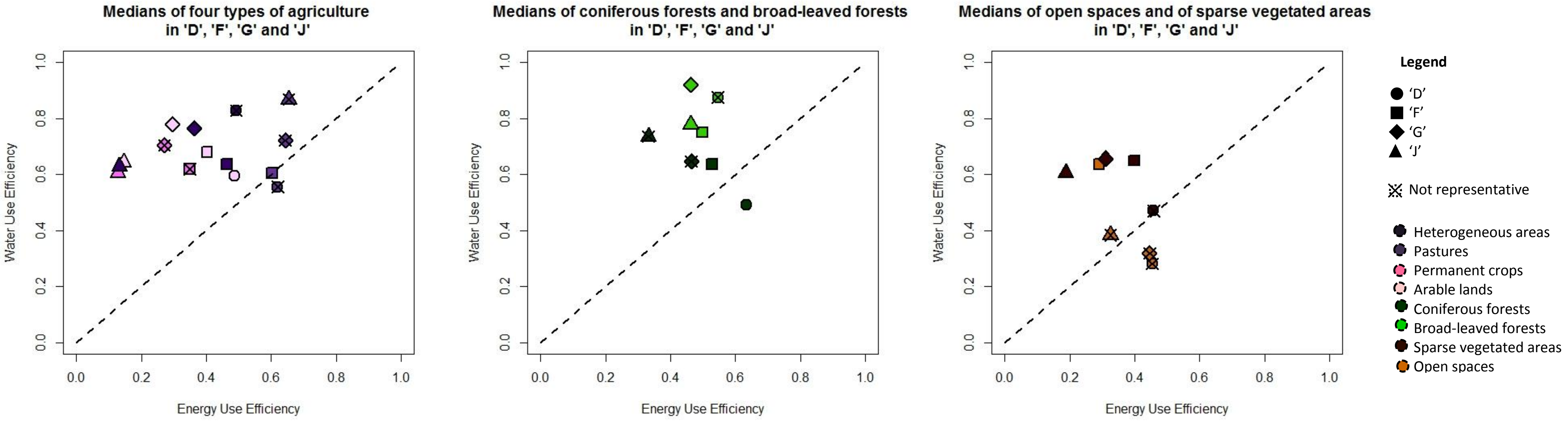

Figure 8. Medians for each sub-type of agriculture, forests and open and sparse vegetated areas in zones of natural vegetation.

6.3.2 Energy and water use efficiency between sub-types of forests

Only in ‘F’ the two sub-types of forests, coniferous and broad-leaved forests, are both considered to be representative (see table 2). They differ significantly in this zone for water and energy use efficiency (see table 5). As figure 8 shows, the difference in water use efficiency between those two types of land cover is much larger than the difference in energy use efficiency. Coniferous forests have a lower water use efficiency but a higher energy use efficiency compared to broad-leaved forests. Therefore, coniferous forests tend to be energy limited while broad-leaved forests tend to be water limited. This difference can be due difference in structure and growing seasons of the trees of both sub-types, or because of difference in distribution of the two types of land cover as coniferous forests occur more in the north of ‘F’ and broad-leaved forests more in the south.

6.3.3 Energy and water use efficiency between sub-types of open and sparse vegetated areas

For open and sparse vegetated areas applies that only in zone ‘F’ two sub-types are representative. Remarkably there is no significant difference in water use efficiency and energy use efficiency between the sub-type open spaces and the sub-type sparse vegetated areas. However, figure 8 shows a clear difference in energy use efficiency. This difference is possibly not significant because of the relative small amount of individual areas of both sub-types which influences the Mann-Whitney U test.

Concluding this paragraph, sub-types often differ significantly in energy use efficiency and sometimes in water use efficiency. Hence, difference in composition of sub-types of a land cover of forests or agriculture between zones of natural vegetation can lead to different results when those two types of land cover are compared in different compositions.

6.4 Water and energy use efficiency of the three land covers in the different seasons

Seasons affect the availability of water and energy as well as it affects the growth of vegetation. Water and energy use efficiency are therefore affected by the seasonal cycle. By comparison of the differences in water and energy use between the seasons and within each zone of natural vegetation it becomes clear what the effect of the seasons is. By comparison of each seasons between the zones of natural vegetation the difference in magnitude of the seasons on the water and energy use efficiency because of differences in climate and biotic circumstances becomes clear.

6.4.1 The role of seasonality within each zone of natural vegetation on the hydrological cycles

In zone ‘D’ it is remarkable that the highest water use efficiencies are found in winter and autumn (see figure 7). In these seasons the amount of actual evapotranspiration is far larger than the amount of precipitation. The energy use efficiency is the highest in these seasons as well. But, in autumn and winter the storage of water, as well as snow, in this zone of natural vegetation is also the biggest. Comparison with literature reveals that the maximum daily evapotranspiration in boreal areas in Canada is the highest in summer, 3.0-3.5 mm day^{-1}, and lowest in winter, 0.5-1.0 mm day^{-1} (Arain et al., 2003). That contradicts the fact that in winter the highest water use efficiency appears. A check of the monthly satellite images of MODIS of the winter seasons shows that some parts of northern Europe become open water surfaces, with high potential and actual evapotranspiration, for no good reason, leading to unreasonably high water use efficiencies. Errors in data of areas in northern Europe in cold seasons of MODIS causes these high water use efficiencies. This explains the high water use efficiency in winter of forests and agriculture in zone ‘F’ as well.

In zone ‘D’ water and energy use efficiency in summer are higher than in spring. The system becomes more efficient with water and energy. That water use efficiency in summer even exceeds the theoretical limit of one is because water stored as snow in the winter melts and is available for evapotranspiration in summer .

The order in magnitude of water use efficiency between spring, summer and autumn is logical in zone ‘F’. In summer the water use efficiency is the highest as water of melted snow from mountainous areas ensures water availability and the temperature is the highest, which leads to a relatively high water use efficiency. In spring, water of melted snow ensures water availability as well, butthe temperatures are lower than in summer and therefore the water use efficiency is lower. In autumn there is no profit of snow melting and the temperatures are lower than in both summer and spring. This gives autumn the lowest water use efficiency. In zone ‘G’ and ‘J’ the same order is seen for water use efficiency of summer, spring and autumn as in zone ‘F’ (see figure 8). Again in autumn the water use efficiency is the lowest and in the summer the highest. This be can explained by the availability of melt water and energy, like is done for zone ‘F’.

6.4.2 The role of seasonality between the zones of natural vegetation on the hydrological cycles

When the summer is compared for the four zones of natural vegetation the median of water use efficiency is highest in zone ‘J’, followed by zone ‘G’, ‘F’ and ‘D’. The water use efficiency increases with temperature as abundant water is available because of melt water from mountainous areas. However, the energy use efficiency in summer in zone ‘J’ is very low, which points to limitation in water. The energy use efficiency in zone ‘D’ and ‘F’ is quite high, which points, in combination with a relative high water use efficiency, to optimal use of water and energy. That agriculture has a higher water use efficiency than forests is probably due to irrigation.

In other seasons the differences are more equal. Zone ‘D’ over all seasons has a higher energy use efficiency compared to the other zones and zone ‘J’ has a relatively low water use efficiency in winter, spring and autumn compared to the others zones. Also the energy use efficiency is the highest in winter. Concluding, it can be stated that energy use efficiency increases when there is less energy available, while water use efficiency increases with abundant water and energy.

6.5 Main results

The main results are that zones of natural vegetation differ significantly, at least for energy use efficiency, and therefore water and energy use efficiency of land covers should be compared not for entire Europe, but for each zone of natural vegetation. The importance of the use of zones of natural vegetation is highlighted, as for entire Europe it is shown that forests have a significant higher energy use efficiency. However, when compared to water and energy use efficiency for each zone of natural vegetation it appears that there is almost no difference in water and energy use efficiency between agriculture and forests.

Between forests and open and sparse vegetated areas differences are found in water and energy use efficiency. Thus, difference in land cover, or vegetation, can affect water and energy use efficiency and vegetated land covers have a higher water and energy use efficiency than less vegetated land covers. However, between agriculture and open and sparse vegetated areas in some zones of natural vegetation significant differences are found for water or energy use efficiency.

The comparison between sub-types shows that sometimes they can have a significantly different water and energy use efficiency. Therefore, the composition of sub-types of a land cover influences water and energy use efficiency.

In seasonality it becomes clear that melt water highly influences the water use efficiency in summer and that in summer, due to the abundant availability of water, the water use efficiency increases with the availability of energy, or in other words increases with temperature. Furthermore, energy use efficiency increases with the limitation of energy, because in colder zones of natural vegetation and in colder seasons a lower energy use efficiency is found than in warmer zones of natural vegetation and seasons.

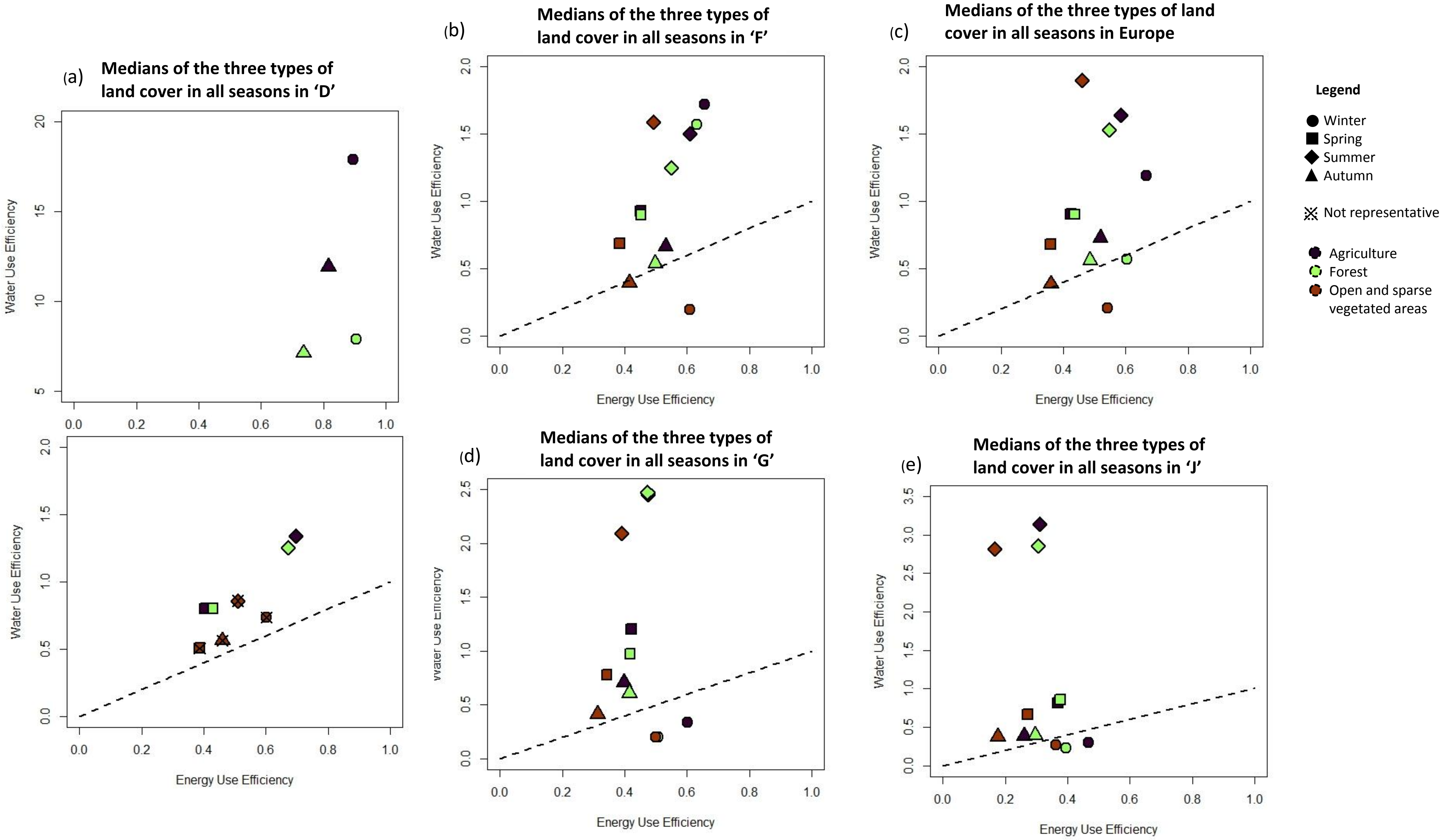

Figure 9. (a,b,d) Medians of the three types of land cover in all seasons in each area of natural vegetation, (c) medians of the three types of land cover in all seasons in Europe.

7. Discussion

7.1 Role of agriculture and forests in the hydrological cycles in entire Europe

As mentioned above, the results shows that energy use efficiency between forests and agriculture differ significantly for entire Europe, but it also shows that this significance is because of difference in distribution of agriculture and forests across Europe. As is shown in table 2 relatively more forests occur in northern Europe, while relatively more agriculture occurs in southern Europe. This difference in distribution means that both types of land cover are exposed to other climate and biotic circumstances. As mentioned in the introduction and theoretical background, climate highly influences the hydrologic cycle as it regulates water and energy transfer. The effect of the differences in climate across Europe on the hydrological cycles is bigger than the effect of land cover on these hydrological cycles. Because after comparison within zones of natural vegetation , or climate zones, almost no significant difference is found in water and energy use efficiency between forests and agriculture. Oceanic currents and the transfer of heat between equator and poles overrule the effects of land cover on climate. This is not surprising, as the classifications of global and continental climate zones can be based solely on temperature, precipitation and evapotranspiration as Budyko (1974) and Köppen (1923; in Kalvova et al., 2003) showed.

7.2 Role of agriculture and forests in the hydrological cycles in zones of natural vegetation

Comparison of agriculture and forests in zones of natural vegetation thus showed that there is almost no difference in water and energy use efficiency. This agrees with research in Sweden where no significant difference in water and energy use efficiency was found between forests and agriculture (Van der Velde et al., 2013). In a research in Australia no difference was found in evapotranspiration between forests and pastures (Williams et al., 2012), which is also a sub-type of agriculture. However, different researches find differences in evapotranspiration when agriculture is convert into forests or vice versa. Like conversion of agriculture into forests can cause lower evapotranspiration (Liu et al., 2008) or higher evapotranspiration (Bosch an Hewlett, 1982; Cao et al., 2008). However, water use efficiency or energy use efficiency are not mentioned in these researches. It could be possible that water and energy use efficiency remain equal while evapotranspiration changes. For example, the albedo and leaf area index influence local temperature; lower albedo and higher leaf area index can cause lower surfaces temperatures, which causes increased precipitation (Bonan, 2002). To reveal what the relation is between precipitation and evapotranspiration in different types of land cover extra research is needed.

The result that between forests or agriculture and sparse and open vegetated areas significant difference in water and energy use efficiency is found is not completely surprising. That vegetation affects evapotranspiration is clear, as well (William et al., 2012; Jones et al., 2012; Peel et al., 2010; Van der Velde et al., 2013). Transpiration of vegetation increases evapotranspiration and thereby water and energy use efficiency. More surprising is that in zones of natural vegetation between forests and open and sparse vegetated areas more often significant differences are found in water and energy use efficiency than between agriculture and open and sparse vegetated areas. Difference in albedo, growing season and rooting depth of forests and agriculture (Bonan, 2008) can explain this. Rooting depth of forests is deeper and therefore forests are able to retain more water than agriculture, which has lower roots (Bonan, 2008). As a consequence, forests are less vulnerable to droughts and are more constant in evapotranspiration throughout the year than agriculture (Feng et al., 2012). Besides, the albedo of forests is higher and growing seasons are longer, especially of coniferous forests, than that of agriculture (Bonan, 2008). A higher albedo induces higher surface temperatures and thus more energy is available for evapotranspiration. A longer growing season means a longer period for evapotranspiration. Summarizing, many factors influence the role of agriculture and forests in the hydrological cycles and cause that forests are more often significantly different in water and energy use efficiency than agriculture compared to open and sparse vegetated areas.

7.3. Differences in role of sub-types of each land cover in the hydrological cycles

For sub-types it also applies that many factors influence their role in the hydrological cycles. The results for sub-types of agriculture where sometimes differences between sub-types in zones of natural vegetation are significant and sometimes not can be due to the complexity of these factors. Some of the significant differences can be explained. Like pastures are deemed to have a high evapotranspiration (Ji et al., 2009; Williams et al., 2012). This is confirmed as the water use efficiency in zone 'F' of pastures is significantly higher than that of arable lands. However, coniferous forests have a higher evapotranspiration than broad-leaved forests (Peel et al., 2010) but in zone 'F' broad-leaved forests have significantly higher water use efficiency and lower energy use efficiency than coniferous forests. An explanation of this discrepancy in the results and in literature is that in zone 'F' broad-leaved forests mainly occur in the southern part while coniferous forests more occur in the northern part.

However, several researches agree that between sub-types of land covers the role in the hydrological cycle can be different (Oudin et al., 2008; Ji et al., 2009; Williams et al., 2012). This agrees with the results from this research and the main conclusion about these findings is that composition of sub-types in a land cover should be taken into account when comparing it to other land covers.

7.4 Effects of seasonality on the role of land covers in the hydrological cycle

Seasonality shows important mechanisms of the Budyko analysis as change in temperature and storage of water is directly translated in alternations in the Budyko analysis. Like in summer the abundant availability of energy and melt water cause high water use efficiencies. A study of small basins in the United States showed the same relationship (Jones et al., 2012). However, when there is not enough energy for evapotranspiration of water a part of the precipitation is runoff (Feng et al., 2012) and therefore water use efficiency drops. Hence, therefore zone 'J' in summer has the highest water use efficiency and zone 'J' the lowest. Besides, irrigation of agriculture increases evapotranspiration (De Ridder and Gualée, 1998) and this explains why agriculture in summer has higher water use efficiency than forests.

Energy use efficiency increases with shortage of energy, or temperature, because potential evapotranspiration equals the evapotranspiration as all energy is used to vaporize water. Hereby is the stock of water abundant. Areas with low temperatures reach the maximum evapotranspiration earlier than areas with high temperatures (Zhang et al., 2001). Thus, water use efficiency is high in winter and high in cold areas, like zone 'D'.

7.5 Review of used methods

To reveal whether land covers within a zone of natural vegetation have similar biotic and climatic circumstances the map of natural vegetation is used (Bohn et al., 2000/2003). Results already showed that energy use efficiency significantly at least differs between the different zones of natural vegetation. Still there can be difference within the zones of natural vegetation. Comparison with a map based ona modified classification of Budyko (Tchebakov et al., 1993) shows that climatic and biotic circumstances within zones are similar. Budyko (1974) created a map with classifications of vegetation zones by placing the dryness index, which is calculated by potential evaporation divided by precipitation (see paragraph 3.1), against potential evaporation. A modification of this map (by Tchebakov et al, 1993) shows many similarities with the classification used in this research (that of Bohn et al. 2000/2003). Only the zone 'G' is not found in the modified classification of Budyko. This zone lays, according to the modified map of Budyko, partly in steppe and partly in temperate forest. The other zones of natural vegetation (Bohn et al., 2000/2003) are similar to the next classification of the modified map of Budyko: ‘D’ is similar to taiga, ‘F’ is similar to temperate forest, and ‘J’ is similar to steppe. Thus it is not strange that between the zones of natural vegetation significant difference is often found in energy and water use efficiency. Notwithstanding that ‘G’ is not classified in the modified map of Budyko, it shows significant differences in water and energy use efficiency between the other zones of natural vegetation. Therefore the classification of zones of natural vegetation can even be considered to be better than the modified map of Budyko to level out effects of climate and biotic components in comparisons of land covers within areas of natural vegetation.

The use of the Budyko analysis as applied by Van der Velde et al. (2013) is reliable to show whether land covers are either energy or water limited and whether or not the land cover is efficient in the use of energy and water. The Budyko analysis is not, however, suitable to entirely explain the role of types of land cover in the hydrological cycles as this is too complex.

8. Conclusion

It can be stated that agriculture and forests do not have different roles in the hydrological cycles. Therewith the hypothesis that agriculture and forest do differ in roles in the hydrological cycles is rejected. Differences in zones of natural vegetation affect the water and energy use efficiency of a land cover and thus affect the role of the land cover in the hydrological cycle. Differences in composition of land cover by sub-types are plausible to cause differences in water and energy use efficiency. Thus, by the comparing of different types of land covers, like agriculture and forests, zones of natural vegetation and the composition of the land covers should be kept equal. Also seasonality causes differences in water and energy use efficiency.

Furthermore, shown is that vegetation affects water and energy use efficiency as there is significant differences between forests and open and sparse vegetated areas. Between agriculture and open and sparse vegetated areas less often significant difference is seen. This difference between forests and agriculture is explained by differences in rooting depth, albedo and length of growing seasons.

Differences in seasons between forests and agriculture shows that irrigation in summer causes that agriculture has a higher water use efficiency than forests. Differences between seasons showed the following relationships within the Budyko analysis: when abundant water and energy is available, water use efficiency increases and energy use efficiency increases when energy availability is limited.

The Budyko analysis as applied by Van der Velde et al. (2013) proved to show main differences between hydrological cycles but is limited in explanation. Therefore, extra research on the components of the Budyko analysis as applied by Van der Velde et al. (2013) is necessary, especially into the relationships between the components in different climate zones and for different types of land cover.

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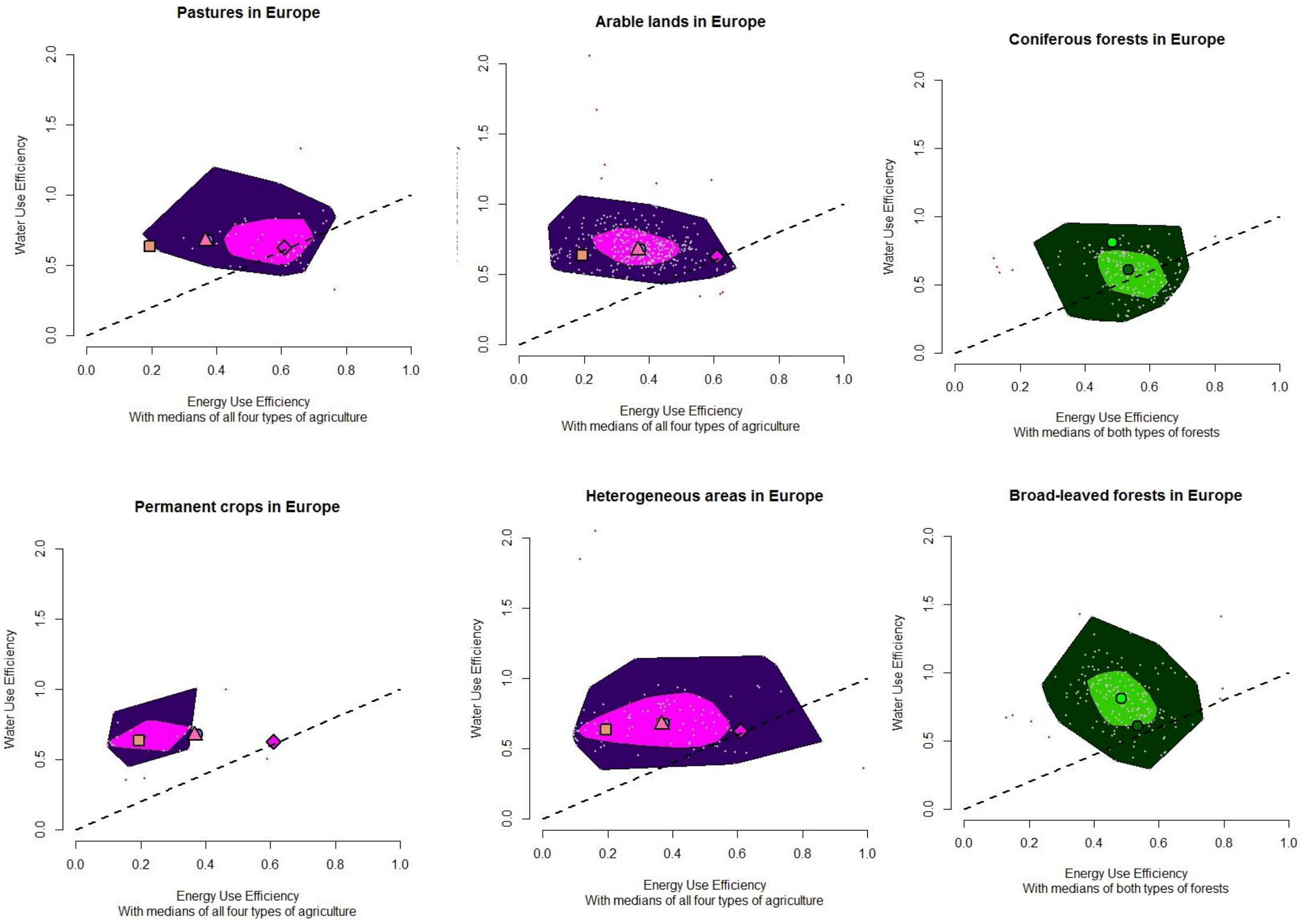
Appendix



Pastures in Europe

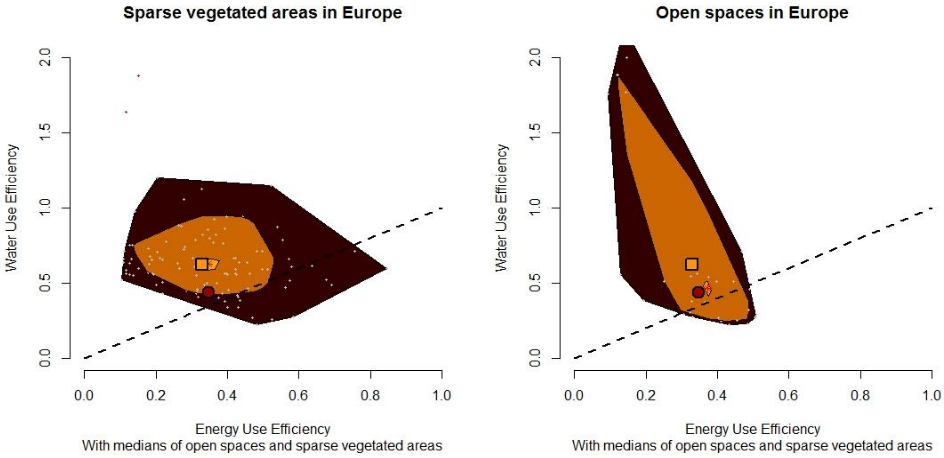
Arable lands in Europe

Coniferous forests in Europe

Permanent crops in Europe

Heterogeneous areas in Europe

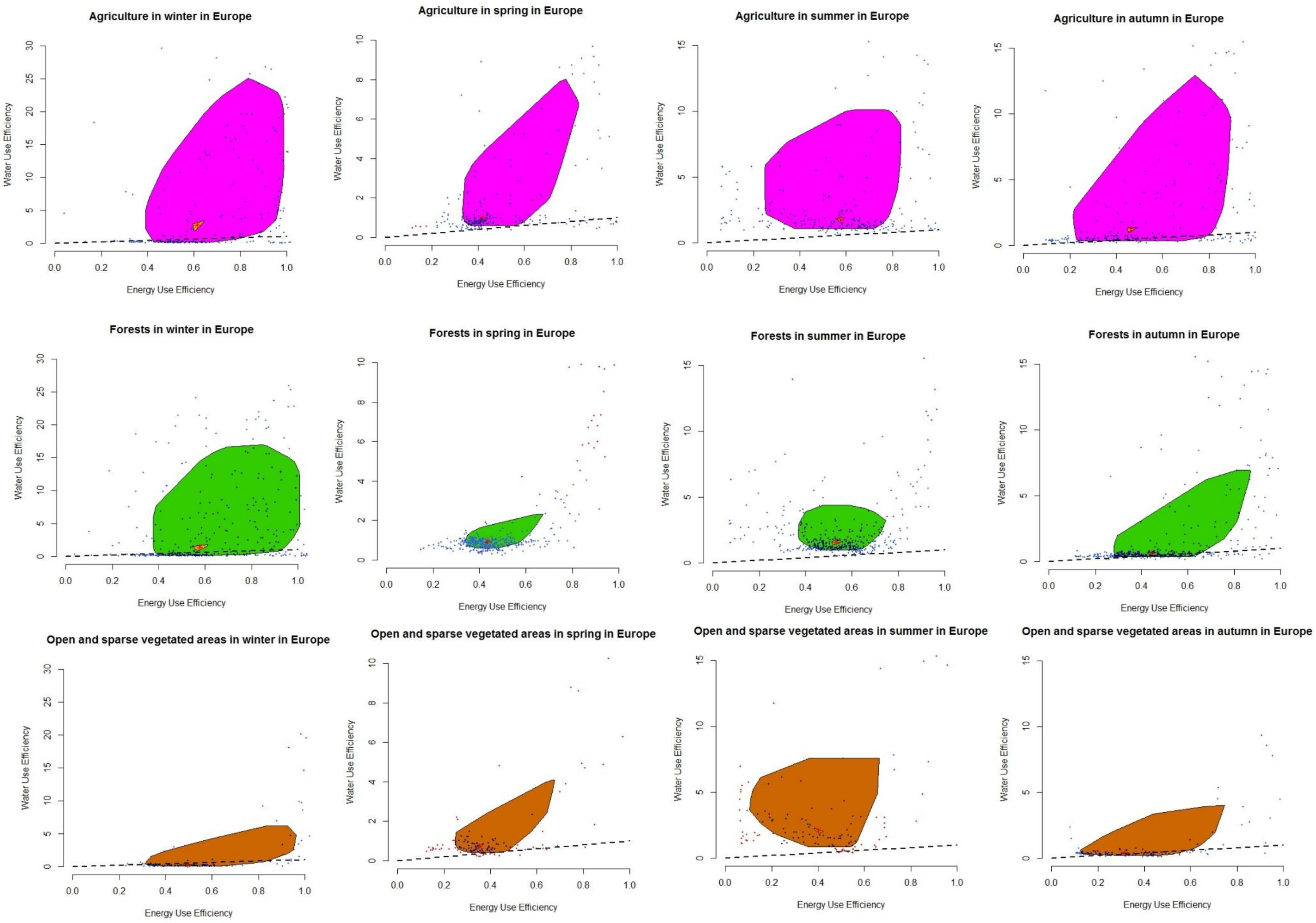
Broad-leaved forests in Europe



Sparse vegetated areas in Europe

Open spaces in Europe

Figure A Bagplots of subtypes of forests and open and sparse vegetated areas in Europe. The individual values inside the loophull are grey and outliers outside the loophull are red.



Agriculture in winter in Europe

Agriculture in spring in Europe

Agriculture in summer in Europe

Agriculture in autumn in Europe

Forests in winter in Europe

Forests in spring in Europe

Forests in summer in Europe

Forests in autumn in Europe

Open and sparse vegetated areas in winter in Europe

Open and sparse vegetated areas in spring in Europe

Open and sparse vegetated areas in summer in Europe

Open and sparse vegetated areas in autumn in Europe

Figure B. Bagplots of the three types of land cover in the four seasons. The individual values inside the loophull are grey and outliers outside the loophull are red.