Response to comments by editor and reviewers on “Environmental controls on seasonal ecosystem evapotranspiration/potential evapotranspiration ratio as determined by the global eddy flux measurements” by Chunwei Liu et al.

We greatly appreciate the review comments and thank the reviewers for their effort. We have addressed all of the comments and present our response below.

The second round of review came back with widely divergent referee judgments. My own judgment is that the paper is an important one, and that it has improved considerably in this revision. I also believe that in the commented version that is attached I was able to address the language issues. The positive reviewer has, nonetheless, come with a number of constructive suggestions that would further improve the manuscript. The more negative reviewer also provided several constructive comments. I believe that address in all of these issues are relatively straightforward to implement (especially relative to the changes made in the last revision). I am therefore returning the manuscript with an instruction for further revisions noted below. If you feel that you are able to make these changes, I will look at the revised version and make my editorial decision without further referee review.
Comments to address from the reviewer who recommended rejection:
The validation of the proposed approach (included as per both reviewers' suggestions) show that the proposed approach does not provide satisfactory results in 3 out of 7 ecosystems (see Fig. 8).

AUTHOR RESPONSE: In the revision, we revised dome discussion on the model validation results. The results were less satisfied in CRO, EBF and OS (Line 235, 315-322) and we offered some explanations.

The results still denote a lack of understanding of the mechanisms driving evapotranspiration in different ecosystems – e.g., the lack of leaves or even plants (for crops) during the winter months. Despite some suggestions on how to handle this issue in the previous round of reviews, the author did not address this point. Rather, in the result section, the authors discuss patterns of average annual Kc, which is not very meaningful when considering temperate and boreal sites (as apparent from Fig.1). Further, they recognize that the seasonal pattern of Kc in evergreen vegetation is more stable in deciduous ecosystems, yet they fail to state why this is the case (needles are retained throughout the year, as opposed to the situation for deciduous trees).

AUTHOR RESPONSE: We have stressed the phenology of different ecosystem in this revision. We discussed seasonal changes of Kc in this revision in relation to LAI (Line 262-266). A Fig on the monthly AET and PET was added.

Second, the validation now introduced as part of the revisions, clearly shows that in several ecosystems the approach does not work very well (Fig. 8). The modelled vs.

simulated evapotranspiration rates, while correlated, do not fall on the 1:1 line (or at least near it) in at least in 3 out of the 7 ecosystems, leading to overestimated or underestimated values. Interestingly, one of the ecosystems in which the approach is not working is the crops, where the FAO model was developed.

AUTHOR RESPONSE: Yes, the results were less satisfactory in CRO, EBF and OS. The under-estimation of CRO modeling was 50 percent lower compared to measured. This error may be because the crops were irrigated during water deficit. The model does not account for added water of irrigation. Meanwhile, the OS has a large proportion of bare soil with low soil water content resulting in an overestimate in modeling ET. The low number sample size (fewer sites than other ecosystem types) may cause a low accuracy of validation in OS and EBF. (Line 315-322)

Third, there are several unclear or incorrect claims. I report here some examples:
L 64 How can PET be considered stable when (the author acknowledge) it depends on temperature and precipitation?

AUTHOR RESPONSE: Yes, the seasonal PET values vary by season. We meant to say that PET values are rather stable in the same season among different years. We have clarified the statement. (Line 64-65).

L 90 The FAO approach has been used for many more crops (and the Kc values are tabulated in Allen 1998, for each and every growth stage).

AUTHOR RESPONSE: Yes, we have modified it. (Line 95)

L 129 How were the 'validation sites' selected? Where are they located?

AUTHOR RESPONSE: We used 30 sites (not used for model developed) with one or two years of data used for model validation. The sites are distributed in the Northern Hemisphere (Latitude between 29-71, and longitude between -125 - 148) (Line 133)

Fig. 5: I am confused by the evergreen broadleaf forest at 60 deg N (one of the two sites among the evergreen broadleaf forested ecosystems). Probably it would be worth to provide a bit more information about the sites, particularly when very few (and hence potentially non-representative) are available

AUTHOR RESPONSE: We tried to presented data from EBF sites located in the Southern Hemisphere. In this revision, we used July data as January if the sites are in the South Hemisphere (Fig 2). Thus, we improved the multiple regression model in Table 1 and Figures 1-7 for EBF.

Comments to address from the reviewer who recommended publication (I am not sure the authors got to see this as the reviewer submitted these confidents in a channel that may not have been available to the authors):

The article of Liu et al. is a needed contribution to studies of evapotranspiration rates across ecosystems and regions. The methodology is consequent and clear. I enjoyed reading the article. The multi-linear models developed by the authors for the ratio of actual evapotranspiration to potential evapotranspiration will be an important tool for hydrologists on the field.

However, some aspects need to be improved. Some key studies are completely missing from their manuscript. Starting by the studies of Budyko (1974) were potential and actual evapotranspiration are put in context. I suggest other important references that could better support the discussion.

AUTHOR RESPONSE: We have added the reference. **（*Line 49*）**

I suggest an inclusion of a Figure that compares water and energy use efficiency for all the ecosystems compared by the authors. This comparison would enable a direct comparison of Kc (AET/PET) and evaporative ratio (AET/P) for all the ecosystems evaluated in the manuscript, enriching the discussion. See Van der Velde et al. (2013).

AUTHOR RESPONSE: The reviewer's suggestion is a good one for future research to understand the control of AET by PET and P at an annual scale. However, this study focuses on Kc – we intended to provide a practical way to estimate ET in a large spatial scale.

Also, general information on the FLUXNET measurements should be included in the manuscript. See below some typical questions.

Any autocorrelation between latitude, precipitation, LAI if not treated independently? I would say that in these Northern Eurasian latitudes as you move northwards you get more rain?

AUTHOR RESPONSE: Yes, we have examined the autocorrelations among different variables. Precipitation, latitude and LAI were independent from each other.

Other aspects along the manuscript are found in detail below:

First paragraph and Line 59-You could mention briefly here that the uncertainty in AET is mainly due to all the factors affecting vegetation AET rates as mentioned by Jaramillo et al., Journal of Hydrology (2013) or Donohue et al. Journal of Hydrology (2007), Hasper et al., Functional Ecology (2015) and by all the climatic and landscape drivers of ET change (See Jaramillo and Destouni, GRL, 2014). Even better, mention the most important.

AUTHOR RESPONSE: We added these important references in the lines 63, 65 and 71.

Line 86-89- Shown by Zhang et al. (2001)

AUTHOR RESPONSE: Yes, we added the reference in line 88.

Line 122- Upfront, please specify the time period of ET availability from FLUXNET, time-scale, how it was obtained, etc. A brief summary could be useful for the general reader that does not know of eddy-flux ET measurements.

AUTHOR RESPONSE: We added the time scale in line 140.

Line 134- in what units are AET and VDP being measured by eddy-flux towers?

AUTHOR RESPONSE: The unit for AET is LE, MJ $m^{-2}d^{-1}$, and for VPD is 100Pa in the original eddy-flux data. We convert it to mm d^{-1} and kPa.

Line 139-How did you estimate all these parameters, Rn, slope of sat, etc? What assumptions of Allen et al. 1998 did you apply? Just explain what assumptions did you use, mention the equation numbers in Allen et al. 1998. What height was wind speed measured at in the towers? With what time scale was PET estimated? Was it later aggregated in time to agree with the AET time scale?

AUTHOR RESPONSE: The Rn is from measured data, the G is calculated as 0.1Rn in daytime and 0.5 Rn at night, the slope of saturation vapour pressure curve is calculated as follows:

$$\Delta = \frac{4098\left[0.6108\exp\left(\frac{17.27T}{T + 237.3}\right)\right]}{(T + 237.3)^2}$$

(Line 142)

Most wind speed measured height is above the canopy. The time scale was daily for PET estimation. Yes, we aggregate the daily PET to monthly PET.

Line 163-Can you send to Supplementary a figure showing how AET and PET vary from month to month. This would enrich the discussion to understand the variations of Kc from month to month!

AUTHOR RESPONSE: We added the monthly AET and PET in Fig 4 that is helpful to understand the difference at different sites in 12 months.

Ecosystem Acronyms-Can you mention again in the results what each of these acronyms are, EBF, GRA, etc, it is difficult to go back to the first explanation every time you use one. Or maybe use easier-to-understand abbreviations.

AUTHOR RESPONSE: We have modified it.(Line 174-178)

Line 174-What do you mean with this?

AUTHOR RESPONSE: Yes, we have modified it. (Line187)

Line 217- by ecosystem, Line 220- measurements with

AUTHOR RESPONSE: Thanks for the tips, we have modified it. (Line 232, 235)

Line 240-I think this should be stated right from the beginning, that some of the flux measurement sites are in irrigated areas! You know, irrigation has been proven to be driving ET changes at the local and even at the global scale. See Jaramillo and Destouni, Science, 2015.So when plotting the figure I just suggest, irrigation could represent much of the high AET or Kc rates. See Van der Velde et al. (2013). Are there other sites that have irrigation in your study? The irrigation issue should be mentioned in the FLUXNET methods.

AUTHOR RESPONSE: Yes, we have improved it. (Line 150, 256-259).

Line 244-You should say that this mainly occurs since as latitude is decreasing, PET increases, but AET increases even more than PET. It is the only way this can happen. This is an interesting finding.

AUTHOR RESPONSE: Yes, we have improved it. (Line 270-272).

Line 248- Mention this in the beginning of the FLUXNET methods.

AUTHOR RESPONSE: Yes, we have improved it. (Line 151).

Line 260- Sorry to be pushy, but again a more updated study showing the domination role of irrigation on ET such as Jaramillo, F., Destouni, G., 2015.

AUTHOR RESPONSE: Yes, we have improved it. (Line 150, 256-259)

Line 266- connect the two sentences

AUTHOR RESPONSE: Yes, we have improved it. (Line291)

Line 284- What is leaf resistance?

AUTHOR RESPONSE: Yes, we have improved it. (Line311)

Table 1- What do blank spaces mean? Non-significant values?

AUTHOR RESPONSE: Yes, we have improved it. (Line523)

Figure 1- Legend is missing

AUTHOR RESPONSE: Yes, we have improved it. (Figure 1)

Figure 3- Explain uncertainty bars, are they one std dev?

AUTHOR RESPONSE: Yes, the bars are standard errors. we have improved it. (Line 537)

Conclusions- the conclusions should state that the models apply to northern temperate and boreal latitudes, and that its extrapolation to other tropical and southern latitudes should be explored.

AUTHOR RESPONSE: Yes, we have improved it. (Line 328).

Some suggested references that could enrich the literature review and discussion mentioned in this review

-Budyko, 1974. Climate and life. Academic Press.

-Donohue, R.J., Roderick, M.L., McVicar, T.R., 2007. On the importance of including vegetation dynamics in Budyko's hydrological model. Hydrol. Earth Syst. Sci. 11, 983–995.

-Hasper, T.B., Wallin, G., Lamba, S., Hall, M., Jaramillo, F., Laudon, H., Linder, S., Medhurst, J.L., Räntfors, M., Sigurdsson, B.D., Uddling, J., 2015. Water use by Swedish boreal forests in a changing climate. Funct. Ecol. n/a-n/a. doi:10.1111/1365-2435.12546

-Jaramillo, F., Destouni, G., 2015. Local flow regulation and irrigation raise global human water consumption and footprint. Science 350, 1248–1251. doi:10.1126/science.aad1010

-Jaramillo, F., Destouni, G., 2014. Developing water change spectra and distinguishing change drivers worldwide. Geophys. Res. Lett. 41, 8377–8386. doi:10.1002/2014GL061848

-Jaramillo, F., Prieto, C., Lyon, S.W., Destouni, G., 2013. Multimethod assessment of evapotranspiration shifts due to non-irrigated agricultural development in Sweden. J. Hydrol. 484, 55–62. doi:10.1016/j.jhydrol.2013.01.010

-van der Velde, Y., Lyon, S.W., Destouni, G., 2013. Data-driven regionalization of river discharges and emergent land cover–evapotranspiration relationships across Sweden. J. Geophys. Res. Atmospheres 118, 2576–2587. doi:10.1002/jgrd.50224

Environmental controls on seasonal ecosystem evapotranspiration/potential evapotranspiration ratio as determined by the global eddy flux measurements

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Abstract: The evapotranspiration/potential evapotranspiration (AET/PET) ratio is traditionally termed as crop coefficient (*Kc*) and has been ~~gradually~~generally used as ecosystem evaporative stress index. In the current hydrology literature, *Kc* has been widely used to as a parameter to estimate crop water demand by water managers, but has not been well examined for other ~~type~~types of ecosystems such as forests and other perennial vegetation. Understanding the seasonal dynamics of this variable for all ecosystems is important to project the ecohydrologcial responses to climate change and accurately quantify water use ~~(AET)~~ at watershed to global scales. This study aimed at deriving monthly *Kc* for multiple vegetation cover types and understanding its environmental controls by analyzing the accumulated global eddy flux (FLUXNET) data. We examined monthly AET/PET data for ~~7~~seven vegetation covers including Open shrubland (OS), Cropland (CRO), Grassland (GRA), Deciduous broad leaf forest (DBF), Evergreen needle leaf forest (ENF) and Evergreen broad leaf forest (EBF), and Mixed forest (MF) across 81 sites. We found that, except for evergreen forests (EBF and ENF), *Kc* values had large seasonal variation across all land covers. The spatial variability of *Kc* was ~~best~~well explained by latitude suggesting site factors ~~has~~are a major control on *Kc*. Seasonally, *Kc* increased significantly with precipitation in the summer months except EBF. Moreover, Leaf Area Index (LAI) significantly influenced monthly *Kc* in all land covers except EBF. During the peak growing season, forests had the highest *Kc* values while Croplands (CRO) had the lowest. We developed a series of ~~multi-variate~~multivariate linear monthly regression models for ~~a large spatial scale~~ *Kc* by land cover type and season using LAI, site latitude and monthly precipitation as independent variables. The *Kc* models are useful for understanding water stress in different

ecosystems under climate change and variability ~~and~~as well as for estimating seasonal ET for large areas with mixed land covers.

Key words: crop coefficient, evapotranspiration, eddy covariance, modeling, water stress

1. Introduction

Evapotranspiration (ET) is one of the major hydrological processes that link energy, water, and carbon cycles in terrestrial ecosystems ~~(Fang et al., 2015;Sun et al., 2010; Sun et al., 2011a; Sun et al., 2011b)~~(Sun et al., 2010; Sun et al., 2011a; Sun et al., 2011b; Fang et al., 2015)~~. In contrast to potential ET (PET) that depends only on atmospheric water demand (Lu et al., 2005), actual evapotranspiration (AET) is arguably the most uncertain ecohydrologic variable for quantifying watershed water budgets~~ . In contrast to potential ET (PET) that depends only on atmospheric water demand (Lu et al., 2005), actual evapotranspiration (AET) is arguably the most uncertain ecohydrologic variable for quantifying watershed water budgets (Baldocchi and Ryu, 2011~~;Fang et al., 2015;Hao et al., 2015a)~~; Fang et al., 2015; Hao et al., 2015a) ~~and for understanding the ecological impacts of climate and land use change (Hao et al., 2015b), and climate variability (Hao et al., 2014). In recent years, one of the most important research questions of ecohydrology focused on how ecosystem dynamics, precipitation, AET, and PET interact in different ecosystems at seasonal and long term scales under a changing environment (Vose et al., 2011).~~

and for understanding the ecological impacts of climate and land use change (Budyko, 1974; Hao et al., 2015b), and climate variability (Hao et al., 2014). In recent years, one of the most important research questions of ecohydrology focused on how ecosystem dynamics, precipitation, AET, and PET interact in different ecosystems at seasonal and long term scales under a changing environment (Vose et al., 2011).

The ratio of AET to PET is traditionally termed as crop coefficient (*Kc*), and has been widely used to as a parameter to estimate crop water demand by water managers (Allen and Pereira, 2009~~;Irmak et al., 2013a)~~; Irmak et al., 2013a).However, this parameter has not been well examined for other ecosystems~~(Zhou et al., 2010;Zhang et al., 2012)~~(Zhou et al., 2010; Zhang et al., 2012)~~. The ratio of AET to PET has also been used as an indicator of regional terrestrial water availability, wetness or drought index, and plant water stress (Anderson et al., 2012;Mu et al., 2012).When the annual AET/PET ratio is close to 1.0, the soil water meets ecosystem water use demand. The ratio of AET/PET or water stress level can be drastically different among different ecosystems in different environmental conditions, because AET is mainly controlled by climate (precipitation and PET) (Zhang et al., 2001) and ecosystem species composition and structure (i.e., leaf area index, rooting depth)~~ . The ratio of AET to PET has also been used as an indicator of regional terrestrial water availability, wetness or drought index, and plant water stress (Anderson et al., 2012; Mu et al., 2012).When the annual AET/PET ratio is close to 1.0, the soil water meets ecosystem water use demand. The ratio of AET/PET or water stress level can be drastically different among different ecosystems in different environmental conditions, because AET is mainly controlled by climate (precipitation and PET) (Zhang et al., 2001; Jaramillo et al., 2013) and ecosystem species composition and structure (i.e., leaf area index, rooting depth) ~~(Sun et al., 2011a)~~(Sun et al., 2011a; Hasper et al., 2016)~~. The seasonal PET values for a particular region are generally stable (Rao et al., 2011;Lu et al., 2005), and deviation of AET/PET from the~~

~~norm indicates variability in AET, which responds to precipitation and water availability when PET is stable (Rao et al., 2011). However, under a changing climate, the monthly AET/PET patterns can be rather complex since both AET and PET are affected by air temperature and precipitation (Sun et al., 2015b;Sun et al., 2015a) and corresponding changes in ecosystem characteristics (e.g., plant species shift) (Sun et al., 2014;Vose et al., 2011).~~

~~In the agricultural water management community, the crop coefficient method remains a popular one for approximating crop water use, despite recent advances in direct ET measurement methods~~ . The same seasonal PET values for a particular region are generally stable among different years (Lu et al., 2005; Rao et al., 2011), and deviation of AET/PET from the norm indicates variability in AET, which responds to precipitation and water availability when PET is stable (Rao et al., 2011). However, under a changing climate, the monthly AET/PET patterns can be rather complex since both AET and PET are affected by air temperature and precipitation (Sun et al., 2015a; Sun et al., 2015b) and corresponding changes in ecosystem characteristics (e.g., plant species shift) (Donohue et al., 2007; Vose et al., 2011; Sun et al., 2014).

In the agricultural water management community, the crop coefficient method remains a popular one for approximating crop water use, despite recent advances in direct ET measurement methods ~~(Baldocchi et al., 2001;Fang et al., 2015;Allen et al., 1998;Allen and Pereira, 2009)~~(Allen et al., 1998; Baldocchi et al., 2001; Allen and Pereira, 2009; Fang et al., 2015). The Kc is termed as single crop coefficient ~~(Allen et al., 1998;Allen et al., 2006;Tabari et al., 2013)~~(Allen et al., 2006; Tabari et al., 2013) which is affected by growing periods, crop species, canopy conductance, and soil evaporation in the field scale ~~(Ding et al., 2015;Allen et al., 1998;Shukla et al., 2014b)~~(Shukla et al., 2014b; Ding et al., 2015). Moreover, *Kc* can be influenced by soil characteristics, vegetative soil cover, height, plant species distribution, and leaf area index in a larger spatial scale ~~(Descheemaeker et al., 2011;Consoli and Vanella, 2014;Anda et al., 2014)~~(Descheemaeker et al., 2011; Anda et al., 2014; Consoli and Vanella, 2014). Although the Food and Agriculture Organization of the United Nations provides various guidelines for several crops (Allen et al., 1998), local measurements are still required to estimate *Kc* to account for local crop varieties and for year-to-year variation in weather conditions ~~(Pereira et al., 2015)~~(Pereira et al., 2015).

~~Although the *Kc* method has been widely used for estimating AET for crops, it has not been widely used for natural ecosystems for the purpose of estimating AET due to limited continuous measurements in these systems. However, as discussed earlier, ecologists and hydrologist have started to use *Kc* to quantify ecosystem stress levels, and consider *Kc* as a variable rather than a constant. Past studies found that *Kc* was influenced by the growing stages and leaf area index for maize (Kang et al., 2003;Ding et al., 2015), winter wheat(Kang et al., 2003;Allen et al., 1998), watermelon (Shukla et al., 2014b), and fruit trees (Marsal et al., 2014b;Taylor et al., 2015). Variations of mid-season crop coefficients for a mixed riparian vegetation dominated by common reed (*Phragmites australis*) could be predicted by growing degree days in central Nebraska, USA(Irmak et al., 2013a). *Kc* ranged from 0.50 to 0.85 for small, open grown shrubs, and from 0.85 to 0.95 for well-developed shrubland. The *Kc* values had a close logarithmic relationship with the canopy cover fraction in the highlands of northern Ethiopia (Descheemaeker et al., 2011). Overall, the non-agricultural ecosystems such as forests, grasslands and~~

~~shrublands are heterogeneous in nature and have high soil water availability. Thus, *Kc* values for natural ecosystems have high variability (Allen et al., 2011;Allen and Pereira, 2009).~~

Although the *Kc* method has been widely used for estimating AET for crops, it has not been widely used for natural ecosystems for the purpose of estimating AET due to limited continuous measurements in these systems (Zhang et al., 2001). However, as discussed earlier, ecologists and hydrologists have started to use *Kc* to quantify ecosystem stress, and have considered *Kc* as a variable rather than a constant. Past studies found that *Kc* was influenced by the growing stages and leaf area index for maize (Kang et al., 2003; Ding et al., 2015), winter wheat (Allen et al., 1998; Kang et al., 2003), watermelon (Shukla et al., 2014b), and fruit trees (Marsal et al., 2014b; Taylor et al., 2015). The *Kc* values are tabulated for each and every growth stage for many more crops all over the world (Allen et al., 1998). Variations of mid-season crop coefficients for a mixed riparian vegetation dominated by common reed (*Phragmites australis*) could be predicted by growing degree days in central Nebraska, USA(Irmak et al., 2013a). *Kc* ranged from 0.50 to 0.85 for small, open grown shrubs, and from 0.85 to 0.95 for well-developed shrubland. The *Kc* values had a close logarithmic relationship with the canopy cover fraction in the highlands of northern Ethiopia (Descheemaeker et al., 2011). Overall, the non-agricultural ecosystems such as forests, grasslands and shrublands are heterogeneous in nature and have high soil water variability. Thus, *Kc* values for natural ecosystems have high variability (Allen and Pereira, 2009; Allen et al., 2011).

Therefore, the goal of this study was to explore how *Kc* varies among multiple ecosystems with various vegetation types over multiple seasons. Another goal was to determine the key biophysical and environmental factors such as latitude, precipitation, and leaf area index that could be used to estimate *Kc*, and if *Kc* can be modeled with a reasonable accuracy ~~in~~at a larger spatial scale. We examined the *Kc* variations for seven land cover types by analyzing the FLUXNET eddy flux data ~~(Baldocchi et al., 2001;Fang et al., 2015)~~(Baldocchi et al., 2001; Fang et al., 2015). Specifically, our objectives were to 1) understand the variation of monthly *Kc* for seven distinct land covers by analyzing the influences of environmental factors (e.g., precipitation, site latitude) on *Kc*; and 2) to develop simple land-cover specific regression models for estimating *Kc* with key environmental factors as independent variables. Specifically, we developed quantitative relationships between environmental factors and *Kc* by land cover ~~type~~ types using data from FLUXNET sites for 8 croplands(CRO), 13 deciduous broad leaf forests(DBF), ~~2~~5 evergreen broad leaf forests(EBF), 34 evergreen needle leaf forests (ENF), 9 grasslands (GRA), 10 mixed forests (MF), and 2 open shrublands (OS). In-depth understanding of the biophysical controls on *Kc* for different ecosystems is important for accurately estimating AET and anticipating the impacts of climate change on ecosystem water stress and water balances.

~~**2. Methods**~~

~~This synthesis study used the LaThuile eddy flux dataset that was developed by FLUXNET (http://fluxnet.ornl.gov/; Fig. 1), a global network that measures the exchanges of carbon dioxide, water vapor, and energy between the biosphere and atmosphere (Baldocchi et al., 2001). The FLUXNET data (Baldocchi et al., 2001;Baldocchi and Ryu, 2011) have been widely used to understand the~~

~~evapotranspiration processes and trend (Fang et al., 2015;Jung et al., 2010), develop AET and ecosystem models (Sun et al., 2011b;Zhang et al., 2016) and map continental-scale ecosystem productivity (Xiao et al., 2014;Zhang et al., 2016).~~

~~We used an existing database that was developed from the eddy flux measurements from 108 sites (Fang et al., 2015). A total of 78 sites were selected to calculate monthly *Kc* for multiple years and develop *Kc* models for different ecosystems, and 30 sites~~

2. Methods

This synthesis study used the LaThuile eddy flux dataset that was developed by FLUXNET (http://fluxnet.ornl.gov/; Fig. 1), a global network that measures the exchanges of carbon dioxide, water vapor, and energy between the biosphere and atmosphere (Baldocchi et al., 2001). The FLUXNET data (Baldocchi et al., 2001; Baldocchi and Ryu, 2011) have been widely used to understand the evapotranspiration processes and trend (Jung et al., 2010; Fang et al., 2015), develop AET and ecosystem models (Sun et al., 2011b; Zhang et al., 2016) and map continental-scale ecosystem productivity (Xiao et al., 2014; Zhang et al., 2016).

We used an existing database that was developed from the eddy flux measurements from 111 sites (Fang et al., 2015). A total of 81 sites were selected to calculate monthly *Kc* for multiple years and develop *Kc* models for different ecosystems, and 30 sites with one or two years of data were used for validating the models. According to the International Geosphere-Biosphere Program (IGBP) land cover classification system, these eddy flux sites represent ~~nine~~seven land cover types: open shrubland (OS), cropland (CRO), grassland (GRA), deciduous broad leaf forest (DBF), evergreen needle leaf forest

(ENF) and evergreen broad leaf forest (EBF), and mixed forest (MF). For each eddy flux tower site (Figure 1), we acquired AET and associated micro-meteorological data, such as vapor pressure deficit, precipitation (P), winds speed, net radiation~~. Potential~~ at daily time scale during 2000-2006. Based on the hypothesis that the soil surface closely resembles an uniform height, actively growing grass, completely shading the ground, potential daily evapotranspiration (PET) was calculated by the FAO Penman–Monteith equation as follows (Allen et al., 1998):

~~$\mathrm{PET} = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$~~

$$\mathrm{PET} = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \qquad (1)$$

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where R_n is net radiation at the cover surface (MJ m^{-2} d^{-1}), G is soil heat flux (MJ m^{-2} d^{-1}), T is mean air temperature (°C), u_2 is wind speed (m s^{-1}), e_s is saturation vapour pressure ($\mathrm{kP_a}$), e_a is actual vapour pressure ($\mathrm{kP_a}$), e_s–e_a is the saturation vapour pressure deficit ($\mathrm{kP_a}$), Δ is slope of saturation vapour pressure curve ($\mathrm{kP_a}$ $°\mathrm{C}^{-1}$), and γ is the psychrometric constant ($\mathrm{kP_a}$ $°\mathrm{C}^{-1}$). Most sites are in the North Hemisphere except three EBF sites.

The monthly crop coefficient (Kc) is defined as the ratio of the measured total monthly AET and the total monthly PET calculated by Equation 1 varies by month and vegetation types (Equation 2). The average annual Kc values were calculated ~~using mean~~by averaging monthly Kc from January to December for ~~the special sites~~each site.

~~$Kc = \frac{ET}{ET_0}$~~ $Kc = \frac{\mathrm{AET}}{\mathrm{PET}}$ (2)

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The LAI time series data for each tower site were downloaded from the Oak Ridge National Laboratory Distributed Active Archive Center (http://daac.ornl.gov/cgi-bin/MODIS/GR_col5_1/mod_viz.html). MODIS LAI ~~was~~data were derived from the fraction of absorbed photosynthetically active radiation (FPAR) that a plant canopy absorbs for photosynthesis and growth in the 0.4–0.7 nm spectral range. The MODIS LAI/FPAR algorithm exploits the spectral information of MODIS surface reflectance at up to seven spectral bands. We extracted monthly LAI data for the ~~time period~~periods from 2000 through 2006 across ~~77~~111 sites using 8-day GeoTIFF data from the Moderate Resolution Imaging Spectroradiometer (MODIS) land subsets' 1-km LAI global fields. We estimated monthly LAI for each flux tower by computing the mean of the 8-day daily values for each month (Fang et al., 2015).

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3. Results

3.1. Seasonal variations and long~~-~~-term means of Kc by land cover

The average monthly *Kc* based on eddy flux data from 2000 to 2007 increased gradually from January to July and then decreased (Fig. 2). Evergreen broad leaf forest (EBF) had the highest mean monthly *Kc* (~~1.01±~~0.~~17) (mean~~97±0.19) (Mean ± standard error) in ~~August.~~December (June for sites in the South Hemisphere). *Kc* for both EBF and ENF varied less seasonally than other forest types (Fig. 2). Standard errors for grassland (GRA~~, –~~), evergreen needle leaf forest (ENF) and open shrubland (OS) (0.10-0.17) were larger than other land cover types (0.03-0.10) for April to August. EBF had higher *Kc* for all seasons than other land covers with a peak value of 0.91 (± 0.~~13~~08) in the ~~summer~~winter season (Fig. 3). In winter seasons, cropland (CRO) and OS had the lowest *Kc*, 0.25 (± 0.006) and 0.22 (± 0.004), respectively.

The mean annual *Kc* was 0.39 (± 0.04), 0.47 (± 0.05), 0.~~79~~75 (± 0.03), 0.45 (± 0.02), 0.57 (± 0.06), 0.45 (± 0.05), and 0.40 (± 0.04) for CRO, deciduous broad leaf forest (DBF~~,~~), EBF, ENF, GRA, mixed forest (MF~~,~~), and OS, respectively. Yearly average precipitation was higher in EBF and DBF than other land covers (Fig. 4). The precipitation ranking by land cover type was EBF> DBF> ~~EBF>~~ MF> GRA> ENF> CRO> OS. Consequently, OS, MF, GRA, CRO and ENF had relatively ~~low~~lower yearly AET (376-425 mm~~). In contrast, CRO~~) than EBF and DBF. Moreover, DBF, EBF and CRO had ~~relatively low precipitation with a high~~higher PET than other vegetation surfaces. The variations for monthly AET and PET were presented in Fig. 4 to the contrasting patterns of these two variables. The AET and PET reached maximum value 2.2-3.3 mm d^{-1} and 3.6-4.7 mm d^{-1} at June or July (December or January for the Southern Hemisphere), respectively.

3.2. Environmental controls on Kc

As indicated in Equation 1, factors such as temperature and solar radiation were ~~using~~used for PET ~~calculation~~calculations, and were not independent to AET/PET. Therefore, ~~–~~we chose other independent factors to simulate AET/PET. ~~Since site~~Site latitude is a readily available variable for a particular location, but is crucial to ~~determine~~ the day length and incoming radiation over the year ~~in the same land cover types, so we explored the relationship between *Kc* and site latitude~~.

The results ~~show~~showed that annual *Kc* was negatively (p<0.05) correlated with ~~the~~ latitude ~~of the sites~~ (Fig.5) for CRO, DBF, ENF, GRA and MF with a determination coefficient (R^2) of 0.83, 0.59 and 0.21, 0.72 and 0.52, respectively. For OS, annual mean

Kc also decreased with the increase in site latitude. Most of the study site ~~latitudes~~ fell between 30°N to 60°N in latitude.

At the seasonal scale, the linear relationships between monthly *Kc* and total monthly precipitation differed among different land cover types (Fig. 6). Monthly *Kc* increased with monthly precipitation in the same ecosystem type with the R^2 ranking from high to low: OS>MF>GRA>ENF>CRO>DBF. The monthly *Kc* for open shrublands (OS) was especially sensitive to precipitation (R^2= 0.69, p<0.001). The monthly *Kc* for EBF was not as sensitive to precipitation as other ecosystems because EBF was generally found in a wet environment with a peak monthly precipitation of 468 mm. Moreover, *Kc* for OS, GRA and MF in relatively drier environments had lower values (Fig. 2). Therefore, *Kc* was closely related to the monthly precipitation.

In addition to growing season, site latitude and monthly precipitation, leaf area index affected the monthly *Kc* (Fig. 7). *Kc* was obviously influenced by ~~the~~ leaf area index (LAI) for all land covers except EBF. The determination coefficients for different land covers were OS> MF=GRA> ENF>DBF>CRO~~>EBF~~. The LAI range was up to 6 m^2 m^{-2} in most land covers, while it only reached 3-4 m^2 m^{-2} in OS and CRO.

3.3. Kc models

A series empirical *Kc* ~~model was~~models have been developed using a multiple linear regression approach with precipitation, leaf area index (LAI), and site latitude as independent variables (Table 1). The monthly precipitation, LAI and site latitude ~~influenced~~influence *Kc* (p<0.1) for most ecosystems studied in different seasons except at EBF in ~~spring, fall~~summer and ~~winter~~fall, and for OS in the spring. As annual precipitation increases, total leaf area increases, therefore *Kc* increases for ENF in all seasons and most of the time for DBF and MF. As site latitude increases, *Kc* values ~~were~~are found to decrease in some periods at CRO, DBF and MF sites. In addition, *Kc* ~~was~~is closely correlated to LAI, site latitude, and monthly precipitation at ENF in fall and OS in winter with R^2 0.55 and 0.99. All land covers ~~had a~~have peak values (0.53± 0.04-1.01 ± 0.17) in the summer months. Except for EBF and GRA, *Kc* values ~~had~~have a close relationship with the monthly precipitation in the summer with R^2 ranging from 0.21 to 0.90. The linear relationships ~~were~~are significant for most vegetation types, suggesting that the regression models (Table 1) can be used to estimate monthly *Kc* if LAI and precipitation for a specific ecosystem are available.

3.4. The validation of the regression models of Kc

All *Kc* multiple regression models for different seasons were validated ~~byecosystem~~by ecosystem type (Fig. 8). The model validation was carried out for 30 sites at a monthly scale. The results showed that the modeled AET calculated from the multiple *Kc* models compared well to measurements with~~ measurmentswith~~ R^2 ranging 0.28-0.56. Among the ecosystems, the model for DBF appeared to be the most accurate one with a ~~R^2 of 0.56~~R^2 of 0.56. However, model validation results for CRO, EBF and OS were not as satisfactory as indicated by the slopes (<1.0 or >1.0) of the regression equations.

4. Discussion

Our study estimated annual and seasonal crop coefficient (*Kc*) for seven land cover types using measured global eddy flux data. We comprehensively evaluated environmental controls (i.e., precipitation, LAI, and site latitude) on annual and growing ~~seasons~~season

Kc and developed a series of multiple linear regression models that can be used for estimating monthly AET over time and space for some vegetation types.

4.1. Crop coefficient variation in different seasons

Several recent studies had shown that *Kc* reached the maximum value in the middle of the growing season in many ecosystems, such as a *P. euphratica* forest in the riparian area ~~(Hou et al., 2010)~~(Hou et al., 2010) in a desert environment, a watermelon crop covered with plastic mulch in Florida ~~(Shukla et al., 2014b;Shukla et al., 2014a)~~(Shukla et al., 2014a; Shukla et al., 2014b), soybean in Nebraska ~~(Irmak et al., 2013b)~~(Irmak et al., 2013b), a temperate desert steppe in Inner Mongolia~~(Zhang et al., 2012)~~(Zhang et al., 2012). As Fig. 2 shows, most of the land covers ~~had~~have peak *Kc* during June to August~~,~~ (In the Northern Hemisphere), while the seasonal patterns of ENF and EBF ~~varied~~vary less than other surfaces. Vegetation growth for both the ENF and EBF sites is active throughout the year. The mean crop ~~coefficients~~coefficient for ~~early period~~ mid-density fruit trees in the early growing season is about 0.5 (Allen et al., 1998~~;~~; Allen and Pereira, 2009) which is similar to those found for DBF or MF during April and May. In addition, the middle season *Kc* values for apple and peach trees with active ground cover were higher than *Kc* for DBF sites during the summer. It is likely that the orchards had higher evapotranspiration rates than natural forests due to irrigation in orchards. We also find that the CRO has relatively low precipitation with a high PET because of irrigation. The irrigation has been proven to be a determine factor to AET at the local and even at the global scale (Jaramillo and Destouni, 2015). Thus, the *Kc* for CRO mainly depends on the irrigation schedule and the primary crops. The loss of leaves on DBF and MF lead to an obvious larger stand error for *Kc* in fall (Fig. 3). The soil water evaporation represents the main water loss, thus key component of *Kc* when the ecosystems lack of leaves or plants in winter (Allen et al., 1998). Moreover, the AET/PET is biologically meaningful in vegetation type distribution (Stephenson, 1998), thus, when LAI becomes small for DBF during winter, the AET/PET reflects the characteristics of evaporation capacity for the ground surface.

4.2. Environmental control factors for Kc

The ecosystem covers and the distributions of the vegetation classes ~~were~~are determined by the latitude ~~(Potter et al., 1993).~~(Potter et al., 1993). Crop coefficient varies predominately by ecosystems, ~~*Kc* will in most cases increase~~and *Kc* increases as the site latitude ~~decreased~~decreases for the same land cover type (Fig. 5). As the latitude ~~decreased~~decreases, the increasing temperature and the solar radiation ~~increased and~~results of PET increasing, thus, the acceleration for AET should be faster than PET. The reason may be the vegetation characteristics ~~would be~~are different for the same land cover type~~.~~ in different latitudes. Models ~~developed~~develop from the FLUXNET data may be best used on flat areas for a ~~given~~specific latitude given that eddy covariance towers were generally installed on flat lands ~~(Baldocchi et al., 2001)~~(Baldocchi et al., 2001). For areas with complex topography, the relationship between *Kc* and site latitude may be more complicated.

Spatial variations of *Kc* are characteristic of ecosystems, but *Kc* is also ~~affected~~effected by climate factors such as rainfall. For example, *Kc* was highly correlated with precipitation for most land covers (Fig. 6).The rainfall is the major source of soil water and AET in natural ecosystems ~~(Parent and Anctil, 2012)~~(Parent and Anctil, 2012). During dry years or periods, a lack of precipitation may cause a reduction of the leaf area index and *Kc* will decrease ~~to response the ecosystem function.~~. During rainy seasons, as, leaf area index and stomatal conductance of trees and rain-fed crops increases, so does *Kc* ~~(Kar et al., 2006;Zeppel et al., 2008)~~(Kar et al., 2006; Zeppel et al., 2008). Irrigation of cropland is a primary mechanism for increasing yield ~~(Du et al., 2015;Fereres and Soriano, 2007)~~(Fereres and Soriano, 2007; Du et al., 2015), so the CRO may have a high monthly *Kc* even at sites with a low precipitation. In contrast, *Kc* does not have a close relationship with precipitation under a wet environment. For example, the EBF site had a monthly precipitation as high as 468 mm/month and generally exceeded monthly AET. In an opposite case for the OS sites, monthly precipitation values were between 0.7 to 69 mm, and *Kc* was highly correlated to monthly precipitation. Moreover, the ~~soil moisture could be a limiting factor to AET, and would affect *Kc* in dry periods. When the~~ time lag between precipitation and soil moisture might cause errors in calculating AET and modeling *Kc* in the long dry or wet season. However, at the monthly scale, previous modeling work (Fang et al., 2015) ~~suggest~~suggests that considering a time lag does not increase the prediction power dramatically (G. Sun Personal communication).

Besides precipitation, leaf area index (LAI) also affects ~~-~~*Kc* in dry and semi-humid ~~area~~areas ~~(Zhang et al., 2012;Kang et al., 2003)~~(Kang et al., 2003; Zhang et al., 2012)~~.~~ ~~Unlike precipitation, LAI directly affects *Kc* in AET calculations (Novák, 2012;Tolk and Howell, 2001). Inter-annual *Kc* values are stable at the GRA and OS sites due to the steady seasonal LAI between years while the plantation forest sites had a more dynamic LAI pattern(Marsal et al., 2014a). As the growth rate of the perennial plants could have~~

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4.3. Modeling the dynamics of Kc

Our study results are consistent with previous studies that show that the growing stage is a key factor for estimating *Kc* in agricultural crops (Allen et al., 1998~~;Zhang et al., 2013;Wei et al., 2015;Alberto et al., 2014)~~; Zhang et al., 2013; Alberto et al., 2014; Wei et al., 2015), fruit trees (Abrisqueta et al., 2013~~;Marsal et al., 2014b)~~; Marsal et al., 2014b), salt grass (Bawazir et al., 2014) and *Populus euphratica Oliv* forest ~~(Hou et al., 2010)~~(Hou et al., 2010). Additionally, our study showed that *Kc* fluctuated more dramatically in DBF, GRA, and MF than other land covers in different seasons (Table 1). Studies also show that monthly leaf stomatal resistance that varies over time is important in estimating the seasonal crop coefficient for a citrus orchard ~~(Taylor et al., 2015).~~(Taylor et al., 2015). The LAI and total monthly precipitation were considered as independent factors ~~(Bond-Lamberty and Thomson, 2010)~~(Bond-Lamberty and Thomson, 2010) and both of them varied in both time and space while the site latitude only represents spatial influences on *Kc*. The modeled AET was acceptable for ~~the different~~

~~land cover types~~DBF, ENF, GRA and MF (Fig. 8), and could be used for monthly AET calculation for large spatial scale and homogeneous ecosystems. The slope of CRO modeling ET to AET was 50 percent lower from 1:1 line may be because the crops was irrigated when the soil lack of water content. Meanwhile, the OS has a large proportion of bare soil with low soil water content may result of an overestimate in modeling ET. The lack of sites samples may cause a low accuracy of validation in OS and EBF molding ET. Thus, the multiple linear regression equations developed from this study take account of both spatial and temporal changes in land surface characteristics and offer a powerful tool to estimate ~~of~~ seasonal ~~dynamic~~dynamics of *Kc* for ~~different~~most ecosystems (Table 1).

5. Conclusions

To seek a convenient method to calculate monthly AET ~~in~~at large spatial ~~scale~~scales, we comprehensively examined the relations between *Kc* and environmental factors using eddy flux data from 81 sites (mainly in the northern hemisphere) with different land covers. We found that *Kc* values varied largely among CRO, DBF, EBF, GRA and MF and over seasons. ~~Precipitation~~Besides EBF, precipitation determined *Kc* in the growing seasons (such as summer), and was chosen as a key variable to calculate *Kc*. We established multiple linear equations for different land covers and seasons to model the dynamics of *Kc* as function of LAI, site latitude and monthly precipitation. These empirical models could be helpful in calculating monthly AET at the regional ~~scales~~scale with readily available climatic data and vegetation structure information. Our study extended the applications of the traditional *Kc* method for estimating crop water use to estimating AET rates and evaporative stress for natural ecosystems. Future studies should further test the applicability of the empirical *Kc* models under extreme climatic conditions and for those under-represented ecosystems by the FLUXNET.

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References

Abrisqueta, I., Abrisqueta, J. M., Tapia, L. M., Munguía, J. P., Conejero, W., Vera, J., and Ruiz-Sánchez, M. C.: Basal crop coefficients for early-season peach trees, Agricultural Water Management, 121, 158-163, http://dx.doi.org/10.1016/j.agwat.2013.02.001, 2013.

Alberto, M. C. R., Quilty, J. R., Buresh, R. J., Wassmann, R., Haidar, S., Correa, T. Q., and Sandro, J. M.: Actual evapotranspiration and dual crop coefficients for dry-seeded rice and hybrid maize grown with overhead sprinkler irrigation, Agricultural Water Management, 136, 1-12, 10.1016/j.agwat.2014.01.005, 2014.

Allen, R. G., Pereira, L. S., Raes, D., and Smith, M.: Crop evapotranspiration, FAO irrigation and drainage paper No. 56, 1998.

Allen, R. G., Pruitt, W. O., Wright, J. L., Howell, T. A., Ventura, F., Snyder, R., Itenfisu, D., Steduto, P., Berengena, J., Yrisarry, J. B., Smith, M., Pereira, L. S., Raes, D., Perrier, A., Alves, I., Walter, I., and Elliott, R.: A recommendation on standardized surface resistance for hourly calculation of reference ETo by the FAO56 Penman-Monteith method, Agricultural Water Management, 81, 1-22, http://dx.doi.org/10.1016/j.agwat.2005.03.007, 2006.

Allen, R. G., and Pereira, L. S.: Estimating crop coefficients from fraction of ground cover and height, Irrigation ~~Science~~Sci, 28, 17-34, DOI 10.1007/s00271-009-0182-z, 2009.

Allen, R. G., Pereira, L. S., Howell, T. A., and Jensen, M. E.: Evapotranspiration information reporting: I. Factors governing measurement accuracy, Agricultural Water Management, 98, 899-920, http://dx.doi.org/10.1016/j.agwat.2010.12.015, 2011.

Anda, A., Silva, J. A. T. d., and Soos, G.: Evapotranspiration and crop coefficient of common reed at the surroundings of Lake Balaton, Hungary, Aquatic Botany, 116, 53-59, 10.1016/j.aquabot.2014.01.008, 2014.

Anderson, M. C., Allen, R. G., Morse, A., and Kustas, W. P.: Use of Landsat thermal imagery in monitoring evapotranspiration and managing water resources, Remote ~~Sensing of Environment~~Sens Environ, 122, 50-65, 2012.

Baldocchi, D., Falge, E., Gu, L., Olson, R., Hollinger, D., Running, S., Anthoni, P., Bernhofer, C., Davis, K., and Evans, R.: FLUXNET: A new tool to study the temporal and spatial variability of ecosystem-scale carbon dioxide, water vapor, and energy flux densities, ~~Bulletin of the American Meteorological Society~~B Am Meteorol Soc, 82, 2415-2434, 2001.

带格式的: 缩进: 左侧: 0 厘米, 悬挂缩进: 2.8 字符

Baldocchi, D. D., and Ryu, Y.: A synthesis of forest evaporation fluxes–from days to years–as measured with eddy covariance, in: Forest Hydrology and Biogeochemistry, Springer, 101-116, 2011.

Bawazir, A. S., Luthy, R., King, J. P., Tanzy, B. F., and Solis, J.: Assessment of the crop coefficient for saltgrass under native riparian field conditions in the desert southwest, Hydrological Processes, 28, 6163-6171, Doi 10.1002/Hyp.10100, 2014.

Bond-Lamberty, B., and Thomson, A.: Temperature-associated increases in the global soil respiration record, Nature, 464, 579-582, 2010.

Budyko, M.: Climate and Life, in, Academic Press, New York, 1974.

Consoli, S., and Vanella, D.: Mapping crop evapotranspiration by integrating vegetation indices into a soil water balance model, Agricultural Water Management, 143, 71-81, 10.1016/j.agwat.2014.06.012, 2014.

Descheemaeker, K., Raes, D., Allen, R., Nyssen, J., Poesen, J., Muys, B., Haile, M., and Deckers, J.: Two rapid appraisals of FAO-56 crop coefficients for semiarid natural vegetation of the northern Ethiopian highlands, ~~Journal Of~~J Arid ~~Environments~~Environ, 75, 353-359, DOI 10.1016/j.jaridenv.2010.12.002, 2011.

Ding, R. S., Tong, L., Li, F. S., Zhang, Y. Q., Hao, X. M., and Kang, S. Z.: Variations of crop coefficient and its influencing factors in an arid advective cropland of northwest China, Hydrological Processes, 29, 239-249, Doi 10.1002/Hyp.10146, 2015.

Donohue, R. J., Roderick, M. L., and McVicar, T. R.: On the importance of including vegetation dynamics in Budyko's hydrological model, Hydrol Earth Syst Sc, 11, 983-995, 2007.

Du, T., Kang, S., Zhang, J., and Davies, W. J.: Deficit irrigation and sustainable water-resource strategies in agriculture for China's food security, J Exp Bot, 66, 2253-2269, 10.1093/jxb/erv034, 2015.

Fang, Y., Sun, G., Caldwell, P., McNulty, S. G., Noormets, A., Domec, J. C., King, J., Zhang, Z., Zhang, X., and Lin, G.: Monthly land cover‐specific evapotranspiration models derived from global eddy flux measurements and remote sensing data, Ecohydrology, 2015.

Fereres, E., and Soriano, M. A.: Deficit irrigation for reducing agricultural water use, ~~Journal of experimental botany~~J Exp Bot, 58, 147-159, 2007.

Hao, L., Sun, G., Liu, Y., Gao, Z., He, J., Shi, T., and Wu, B.: Effects of precipitation on grassland ecosystem restoration under grazing exclusion in Inner Mongolia, China, Landscape ~~Ecology~~Ecol, 1-17, 10.1007/s10980-014-0092-1, 2014.

Hao, L., Sun, G., Liu, Y., and Qian, H.: Integrated Modeling of Water Supply and Demand under Management Options and Climate Change Scenarios in Chifeng City, China, JAWRA Journal of the American Water Resources Association, 51, 655-671, 2015a.

Hao, L., Sun, G., Liu, Y., Wan, J., Qin, M., Qian, H., Liu, C., Zheng, J., John, R., and Fan, P.: Urbanization dramatically altered the water balances of a paddy field-dominated basin in southern China, ~~Hydrology and~~Hydrol Earth ~~System Sciences~~Syst Sc, 19, 3319-3331, 2015b.

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带格式的: 缩进：左侧： 0 厘米，悬挂缩进：2.8 字符

Hasper, T. B., Wallin, G., Lamba, S., Hall, M., Jaramillo, F., Laudon, H., Linder, S., Medhurst, J. L., Rantfors, M., Sigurdsson, B. D., and Uddling, J.: Water use by Swedish boreal forests in a changing climate, Funct Ecol, 30, 690-699, 10.1111/1365-2435.12546, 2016.

Hou, L. G., Xiao, H. L., Si, J. H., Xiao, S. C., Zhou, M. X., and Yang, Y. G.: Evapotranspiration and crop coefficient of Populus euphratica Oliv forest during the growing season in the extreme arid region northwest China, Agricultural Water Management, 97, 351-356, 2010.

Irmak, S., Kabenge, I., Rudnick, D., Knezevic, S., Woodward, D., and Moravek, M.: Evapotranspiration crop coefficients for mixed riparian plant community and transpiration crop coefficients for Common reed, Cottonwood and Peach-leaf willow in the Platte River Basin, Nebraska-USA, Journal of Hydrology, 481, 177-190, 10.1016/j.jhydrol.2012.12.032, 2013a.

Irmak, S., Odhiambo, L. O., Specht, J. E., and Djaman, K.: Hourly And Daily Single And Basal Evapotranspiration Crop Coefficients as a Function Of Growing Degree Days, Days after Emergence, Leaf Area Index, Fractional Green Canopy Cover, And Plant Phenology for Soybean, T Asabe, 56, 1785-1803, 2013b.

Jaramillo, F., Prieto, C., Lyon, S. W., and Destouni, G.: Multimethod assessment of evapotranspiration shifts due to non-irrigated agricultural development in Sweden, Journal Of Hydrology, 484, 55-62, 10.1016/j.jhydrol.2013.01.010, 2013.

Jaramillo, F., and Destouni, G.: Local flow regulation and irrigation raise global human water consumption and footprint, Science, 350, 1248-1251, 10.1126/science.aad1010, 2015.

Jung, M., Reichstein, M., Ciais, P., Seneviratne, S. I., Sheffield, J., Goulden, M. L., Bonan, G., Cescatti, A., Chen, J., and De Jeu, R.: Recent decline in the global land evapotranspiration trend due to limited moisture supply, Nature, 467, 951-954, 2010.

Kang, S., Gu, B., Du, T., and Zhang, J.: Crop coefficient and ratio of transpiration to evapotranspiration of winter wheat and maize in a semi-humid region, Agricultural water management, 59, 239-254, 2003.

Kar, G., Verma, H. N., and Singh, R.: Effects of winter crop and supplemental irrigation on crop yield, water use efficiency and profitability in rainfed rice based cropping system of eastern India, Agricultural Water Management, 79, 280-292, DOI 10.1016/j.agwat.2005.03.001, 2006.

Lu, J., Sun, G., McNulty, S. G., and Amatya, D.: A comparison of six potential evapotranspiration methods for regional use in the Southeastern United States, ~~2005.~~J Am Water Resour As, 41, 621-633, 2005.

Marsal, J., Casadesus, J., Lopez, G., Girona, J., and Stöckle, C.: Disagreement between tree size and crop coefficient in'conference'pear: comparing measurements by a weighing Lysimeter and prediction by Cropsyst, Acta horticulturae, 2014a.

Marsal, J., Johnson, S., Casadesus, J., Lopez, G., Girona, J., and Stöckle, C.: Fraction of canopy intercepted radiation relates differently with crop coefficient depending on the season and the fruit tree species, Agricultural and Forest Meteorology, 184, 1-11, http://dx.doi.org/10.1016/j.agrformet.2013.08.008, 2014b.

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Mu, Q., Zhao, M., Kimball, J., McDowell, N., and Running, S.: A remotely sensed global terrestrial drought severity index, in: Evapotranspiration in the Soil-plant-atmosphere System, AGU Fall Meeting Abstracts, 2012, L02, 2012.

Novák, V.: Evapotranspiration in the Soil-plant-atmosphere System, Springer Science & Business Media, 2012.

Parent, A. C., and Anctil, F.: Quantifying evapotranspiration of a rainfed potato crop in South-eastern Canada using eddy covariance techniques, Agricultural Water Management, 113, 45-56, DOI 10.1016/j.agwat.2012.06.014, 2012.

Pereira, L. S., Allen, R. G., Smith, M., and Raes, D.: Crop evapotranspiration estimation with FAO56: Past and future, Agricultural Water Management, 147, 4-20, 2015.

Potter, C. S., Randerson, J. T., Field, C. B., Matson, P. A., Vitousek, P. M., Mooney, H. A., and Klooster, S. A.: Terrestrial ecosystem production: a process model based on global satellite and surface data, Global ~~Biogeochemical Cycles~~Biogeochem Cy, 7, 811-841, 1993.

Rao, L., Sun, G., Ford, C., and Vose, J.: Modeling potential evapotranspiration of two forested watersheds in the southern Appalachians, ~~Transactions of the ASABE~~T Asabe, 54, 2067-2078, 2011.

Shukla, S., Shrestha, N. K., and Goswami, D.: Evapotranspiration And Crop Coefficients for Seepage-Irrigated Watermelon with Plastic Mulch In a Sub-Tropical Region, ~~Transactions Of the~~T Asabe, 57, 1017-1028, 2014a.

Shukla, S., Shrestha, N. K., Jaber, F. H., Srivastava, S., Obreza, T. A., and Boman, B. J.: Evapotranspiration and crop coefficient for watermelon grown under plastic mulched conditions in sub-tropical Florida, Agricultural Water Management, 132, 1-9, 10.1016/j.agwat.2013.09.019, 2014b.

Stephenson, N.: Actual evapotranspiration and deficit: biologically meaningful correlates of vegetation distribution across spatial scales, J Biogeogr, 25, 855-870, 1998.

Sun, G., Noormets, A., Gavazzi, M. J., McNulty, S. G., Chen, J., Domec, J. C., King, J. S., Amatya, D. M., and Skaggs, R. W.: Energy and water balance of two contrasting loblolly pine plantations on the lower coastal plain of North Carolina, USA, Forest ~~Ecology And Management~~Ecol Manag, 259, 1299-1310, DOI 10.1016/j.foreco.2009.09.016, 2010.

Sun, G., Alstad, K., Chen, J. Q., Chen, S. P., Ford, C. R., Lin, G. H., Liu, C. F., Lu, N., McNulty, S. G., Miao, H. X., Noormets, A., Vose, J. M., Wilske, B., Zeppel, M., Zhang, Y., and Zhang, Z. Q.: A general predictive model for estimating monthly ecosystem evapotranspiration, Ecohydrology, 4, 245-255, Doi 10.1002/Eco.194, 2011a.

Sun, G., Caldwell, P., Noormets, A., McNulty, S. G., Cohen, E., Moore Myers, J., Domec, J. C., Treasure, E., Mu, Q., and Xiao, J.: Upscaling key ecosystem functions across the conterminous United States by a water‐centric ecosystem model, Journal of Geophysical Research: Biogeosciences, 116, 2011b.

Sun, S., Chen, H., Ju, W., Yu, M., Hua, W., and Yin, Y.: On the attribution of the changing hydrological cycle in Poyang Lake Basin, China, Journal of Hydrology, 514, 214-225, 2014.

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Sun, S., Sun, G., Caldwell, P., McNulty, S., Cohen, E., Xiao, J., and Zhang, Y.: Drought impacts on ecosystem functions of the US National Forests and Grasslands: Part II assessment results and management implications, Forest ~~Ecology and Management~~Ecol Manag, 353, 269-279, 2015a.

Sun, S., Sun, G., Caldwell, P., McNulty, S. G., Cohen, E., Xiao, J., and Zhang, Y.: Drought impacts on ecosystem functions of the US National Forests and Grasslands: Part I evaluation of a water and carbon balance model, Forest ~~Ecology and Management~~Ecol Manag, 353, 260-268, 2015b.

Tabari, H., Grismer, M. E., and Trajkovic, S.: Comparative analysis of 31 reference evapotranspiration methods under humid conditions, Irrigation ~~Science~~Sci, 31, 107-117, 2013.

Taylor, N., Mahohoma, W., Vahrmeijer, J., Gush, M., Allen, R. G., and Annandale, J. G.: Crop coefficient approaches based on fixed estimates of leaf resistance are not appropriate for estimating water use of citrus, Irrigation ~~Science~~Sci, 33, 153-166, 2015.

Tolk, J. A., and Howell, T. A.: Measured and simulated evapotranspiration of grain sorghum grown with full and limited irrigation in three high plains soils, Transactions Of the Asae, 44, 1553-1558, 2001.

Vose, J. M., Sun, G., Ford, C. R., Bredemeier, M., Otsuki, K., Wei, X., Zhang, Z., and Zhang, L.: Forest ecohydrological research in the 21st century: what are the critical needs?, Ecohydrology, 4, 146-158, 2011.

Wei, Z., Paredes, P., Liu, Y., Chi, W. W., and Pereira, L. S.: Modelling transpiration, soil evaporation and yield prediction of soybean in North China Plain, Agricultural Water Management, 147, 43-53, http://dx.doi.org/10.1016/j.agwat.2014.05.004, 2015.

Xiao, J., Ollinger, S. V., Frolking, S., Hurtt, G. C., Hollinger, D. Y., Davis, K. J., Pan, Y., Zhang, X., Deng, F., and Chen, J.: Data-driven diagnostics of terrestrial carbon dynamics over North America, Agricultural and Forest Meteorology, 197, 142-157, 2014.

Zeppel, M. J. B., Macinnis-Ng, C. M. O., Yunusa, I. A. M., Whitley, R. J., and Earnus, D.: Long term trends of stand transpiration in a remnant forest during wet and dry years, Journal Of Hydrology, 349, 200-213, DOI 10.1016/j.jhydrol.2007.11.001, 2008.

Zhang, B., Liu, Y., Xu, D., Zhao, N., Lei, B., Rosa, R. D., Paredes, P., Paço, T. A., and Pereira, L. S.: The dual crop coefficient approach to estimate and partitioning evapotranspiration of the winter wheat–summer maize crop sequence in North China Plain, Irrigation ~~Science~~Sci, 31, 1303-1316, 2013.

Zhang, F., Zhou, G. S., Wang, Y., Yang, F. L., and Nilsson, C.: Evapotranspiration and crop coefficient for a temperate desert steppe ecosystem using eddy covariance in Inner Mongolia, China, Hydrological Processes, 26, 379-386, 2012.

Zhang, L., Dawes, W. R., and Walker, G. R.: Response of mean annual evapotranspiration to vegetation changes at catchment scale, Water Resources Research, 37, 701-708, 2001.

Zhang, Y., Song, C., Sun, G., Band, L. E., McNulty, S., Noormets, A., Zhang, Q., and Zhang, Z.: Development of a coupled carbon and water model for estimating global gross primary productivity and evapotranspiration based on eddy flux and remote sensing data, Agricultural and Forest Meteorology, 223, 116-131, 2016.

Zhou, L., Zhou, G. S., Liu, S. H., and Sui, X. H.: Seasonal contribution and interannual variation of evapotranspiration over a reed marsh (Phragmites australis) in Northeast China from 3-year eddy covariance data, Hydrological Processes, 24, 1039-1047, 2010.

Table 1 Multiple linear regression relationships among crop coefficient and LAI, precipitation and site latitude in different seasons.

IGBP	season	*N*	R^2	*Kc*	*b*	a_1	a_2	a_3
CRO	Spring	24	0.16	0.31	0.242***	0.141*		
	Summer	24	0.21	0.57	0.331**			0.0033*
	Fall	23	0.78	0.48	0.036	0.472***		
	Winter	21	0.36	0.26	0.920***		-0.0141**	
DBF	Spring	39	0.49	0.30	0.479**		-0.0076*	0.0022***
	Summer	39	0.42	0.65	0.536***			0.0011***
	Fall	39	0.13	0.60	0.462***			0.0014*
	Winter	39	0.15	0.30	0.713***		-0.0094*	
EBF	Spring	~~6~~15	~~-~~0.25	0.~~66~~74	0.~~663~~875***		-0.0050*	
	Summer	~~6~~15	~~0.93~~-	0.~~97~~91	~~-2.10**~~0.911***		~~0.059**~~	
	Fall	~~4~~15	-	0.~~77~~80	0.~~772**~~798***			
	Winter	~~3~~15	~~-~~0.42	0.~~52~~72	0.~~519**~~676***	0.050*	-0.0050**	
ENF	Spring	96	0.39	0.37	0.225***	0.060***		0.0017***
	Summer	99	0.59	0.49	0.211***	0.053***		0.0020***
	Fall	98	0.55	0.52	-0.040	0.066***	0.0049*	0.0025***
	Winter	92	0.21	0.44	0.293***	0.084*		0.0010*
GRA	Spring	27	0.48	0.45	0.237***			0.0052***
	Summer	27	0.23	0.86	0.572***	0.110*		
	Fall	27	0.30	0.76	0.499***	0.123**		
	Winter	27	0.26	0.41	0.256**			0.0038**
MF	Spring	30	0.67	0.31	0.099**	0.188***		0.0012***
	Summer	30	0.40	0.61	0.372***			0.0029***
	Fall	30	0.54	0.58	0.250***	0.071***		0.0018***
	Winter	30	0.13	0.33	0.961**		-0.0136*	
OS	Spring	6	-	0.23	0.230***			
	Summer	6	0.90	0.35	-5.419*		0.1005*	0.0026*
	Fall	6	0.88	0.42	-9.921*	0.051*	0.1828*	
	Winter	6	0.99	0.14	-4.919*	0.629*	0.0882*	0.0032*

Note: *N* is the number of observations used, R^2 the determination coefficient, Kc_{Ave} is the average *Kc* for seasons. *b* is the intercept of the multiple linear equation, a_1 the coefficient of LAI, a_2 the coefficient of site latitude (Absolute values), a_3 the coefficient of precipitation. IGBP is the International Geosphere-Biosphere Program land cover classification system: cropland (CRO), deciduous broad leaf forest (DBF), evergreen broad leaf forest (EBF), evergreen needle leaf forest (ENF), grassland (GRA), mixed forest (MF), and open shrubland (OS). ***, **, * stand for

$p<0.001$, $p<0.01$, $p<0.1$~~.~~, and the blank spaces mean non-significant. In the North Hemisphere, Spring is the month of February, March and April; Summer is the month of May, June and July; Fall is August, September and October; Winter is November, December and January. In the South Hemisphere, Spring is August, September and October; Summer is November, December and January; Fall is February, March and April; and winter is May, June and July.

Figure captions

Fig. 1 Location of eddy flux sites from which climate and evapotranspiration data are collected.

Fig. 2 The variation of *Kc* for the different IGBP ~~code. The error bras are stand errors among different sites~~codes. The error bars are standard errors among different sites. The seven vegetation covers are Open shrubland (OS), Cropland (CRO), Grassland (GRA), Deciduous broad leaf forest (DBF), Evergreen needle leaf forest (ENF) and Evergreen broad leaf forest (EBF), and Mixed forest (MF). For sites in the South Hemisphere, July data were plotted as in January.

Fig.3 Average *Kc* at spring, summer, fall and winter in different vegetation types. The error ~~bras~~bars are ~~stand~~standard errors among different sites. Spring is the month of February, March and April; Summer is the month of May, June and July; Fall is August, September and October; Winter is November, December and January. In the South Hemisphere, Spring is August, September and October; Summer is November, December and January; Fall is February, March and April; and winter is May, June and July.

Fig.4 ~~Annual~~ Monthly AET and PET, and annual total precipitation (P), AET and PET ~~in~~for different vegetation types. The error ~~bras~~bars are ~~stand~~standard errors among different sites.

Fig. 5 Variation of annual *Kc* at different latitude (Lat). (a) ~~stand for~~ cropland (CRO), deciduous broad leaf forest (DBF), evergreen broad leaf forest (EBF), and (b) evergreen needle leaf forest (ENF), grassland (GRA), mixed forest (MF), and open shrubland (OS). The absolute values of the latitude were used in EBF for sites in the ~~southern hemisphere sites~~ Southern Hemisphere and all the determination ~~coefficient~~coefficients (R^2) listed in the figure were significant (p<0.05).

Fig. 6 Relationships between the average monthly *Kc* and ~~the total~~ monthly precipitation (P, mm) for different vegetation surfaces. Figures (a)~(g) represent ~~for~~ cropland (CRO), deciduous broad leaf forest (DBF), evergreen broad leaf forest (EBF), evergreen needle leaf forest (ENF), grassland (GRA), mixed forest (MF), and open shrubland (OS~~).~~), respectively. All the determination ~~coefficient~~coefficients (R^2) listed in the figure were significant (p<0.001~~)~~).

Fig. 7 Relationships between the average monthly *Kc* and leaf area index for different vegetation surfaces. Figures (a)~(g) stand for cropland (CRO), deciduous broad leaf forest (DBF), evergreen broad leaf forest (EBF), evergreen needle leaf forest (ENF), grassland (GRA), mixed forest (MF), and open shrubland (OS). All the determination ~~coefficient~~coefficients (R^2) listed in the figure were significant (p<0.~~001)~~05).

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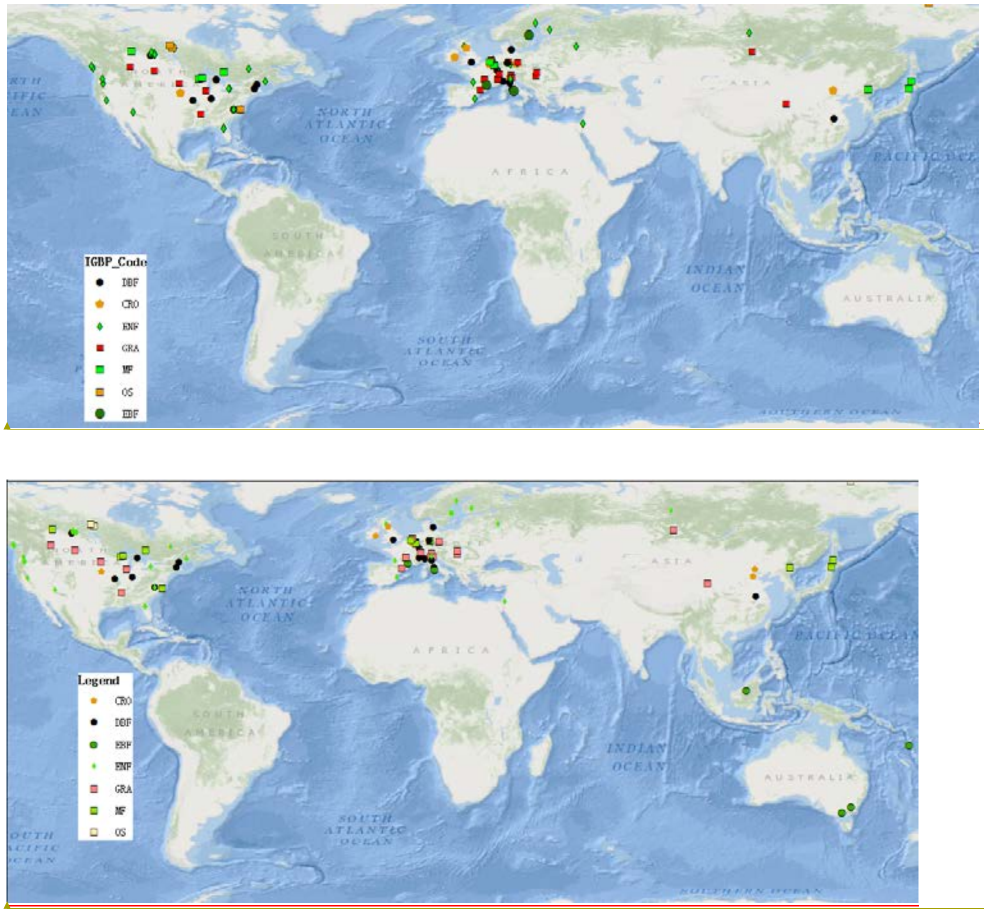

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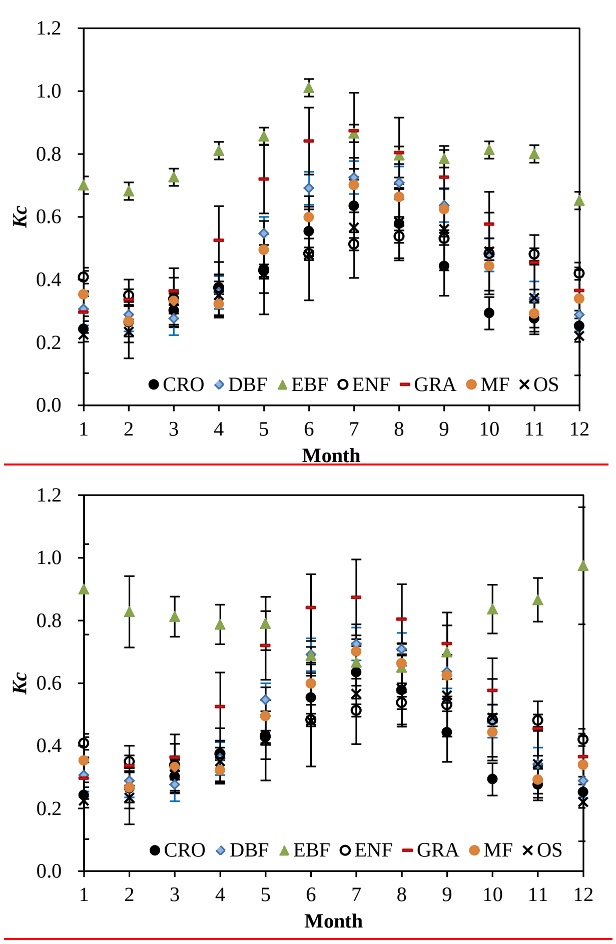

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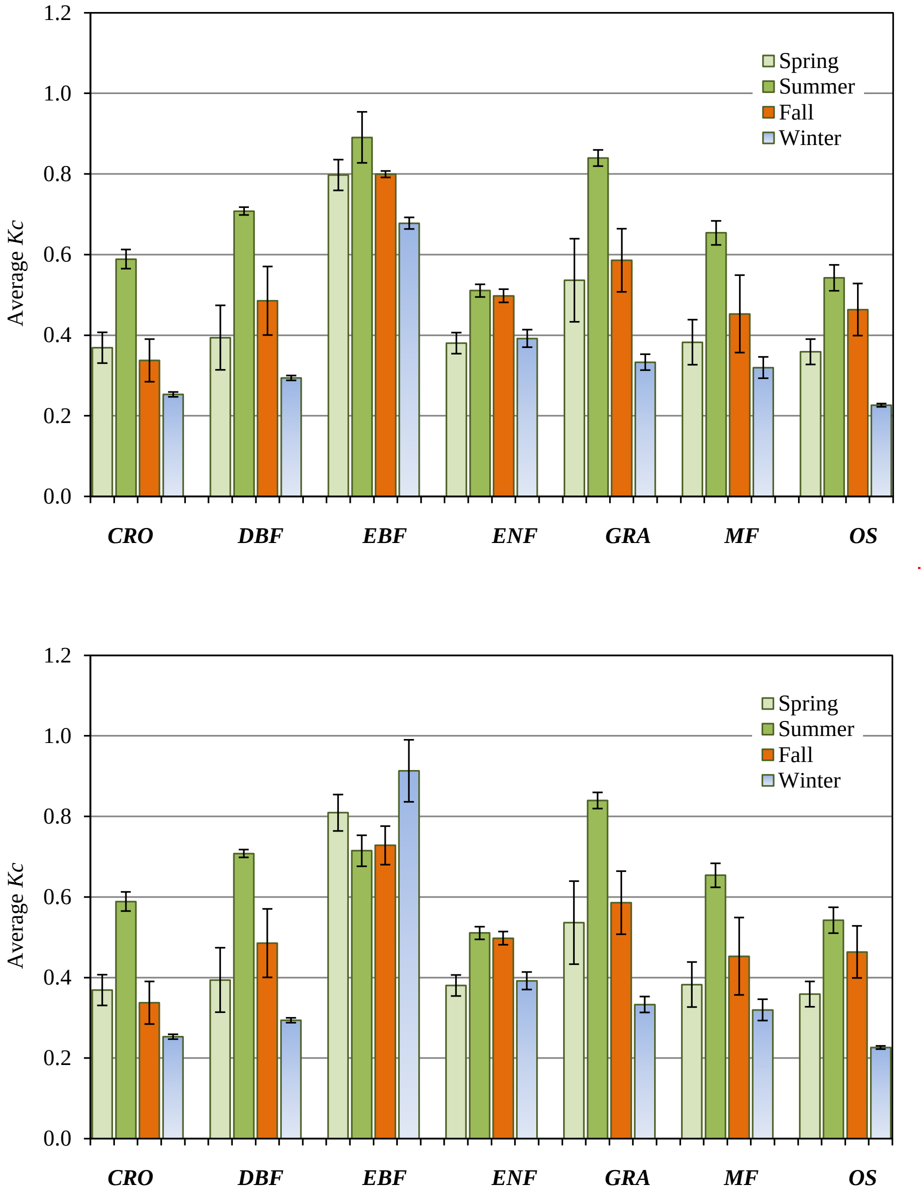

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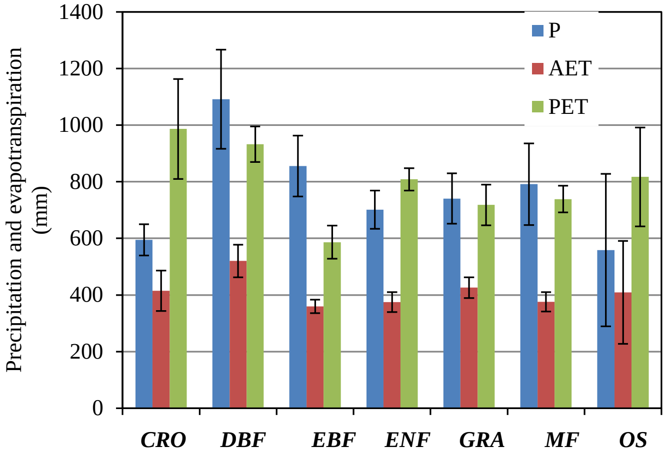
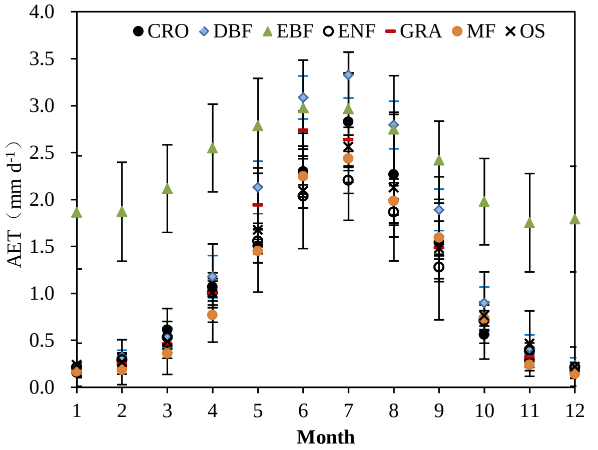
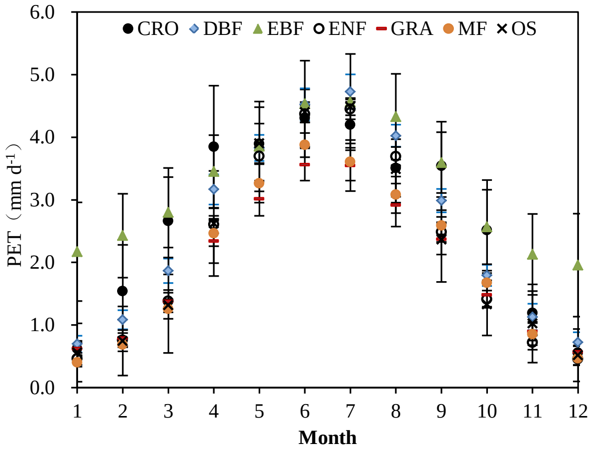
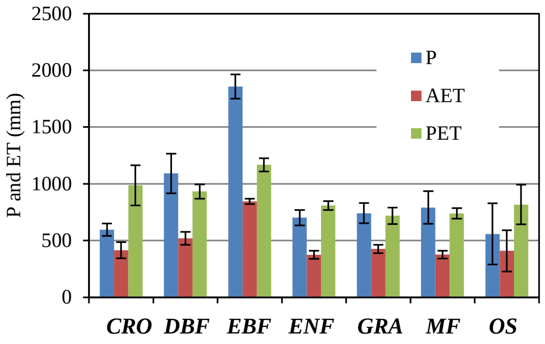


1400
1200
1000
800
600
400
200
0
Precipitation and evapotranspiration (mm)
P
AET
PET
CRO
DBF
EBF
ENF
GRA
MF
OS


●CRO ◇DBF ▲EBF ○ENF ▬GRA ●MF ×OS
AET（mm d-1）
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1 2 3 4 5 6 7 8 9 10 11 12
Month


●CRO ◇DBF ▲EBF ○ENF ▬GRA ●MF ×OS
PET（mm d-1）
6.0
5.0
4.0
3.0
2.0
1.0
0.0
1 2 3 4 5 6 7 8 9 10 11 12
Month


P
AET
PET
P and ET (mm)
2500
2000
1500
1000
500
0
CRO DBF EBF ENF GRA MF OS

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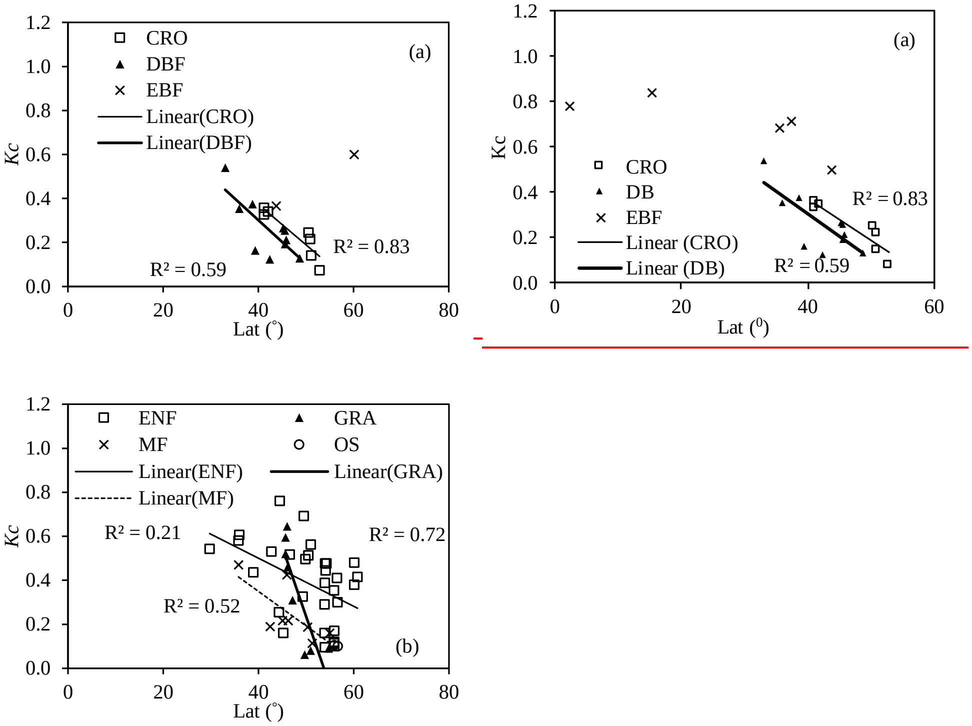

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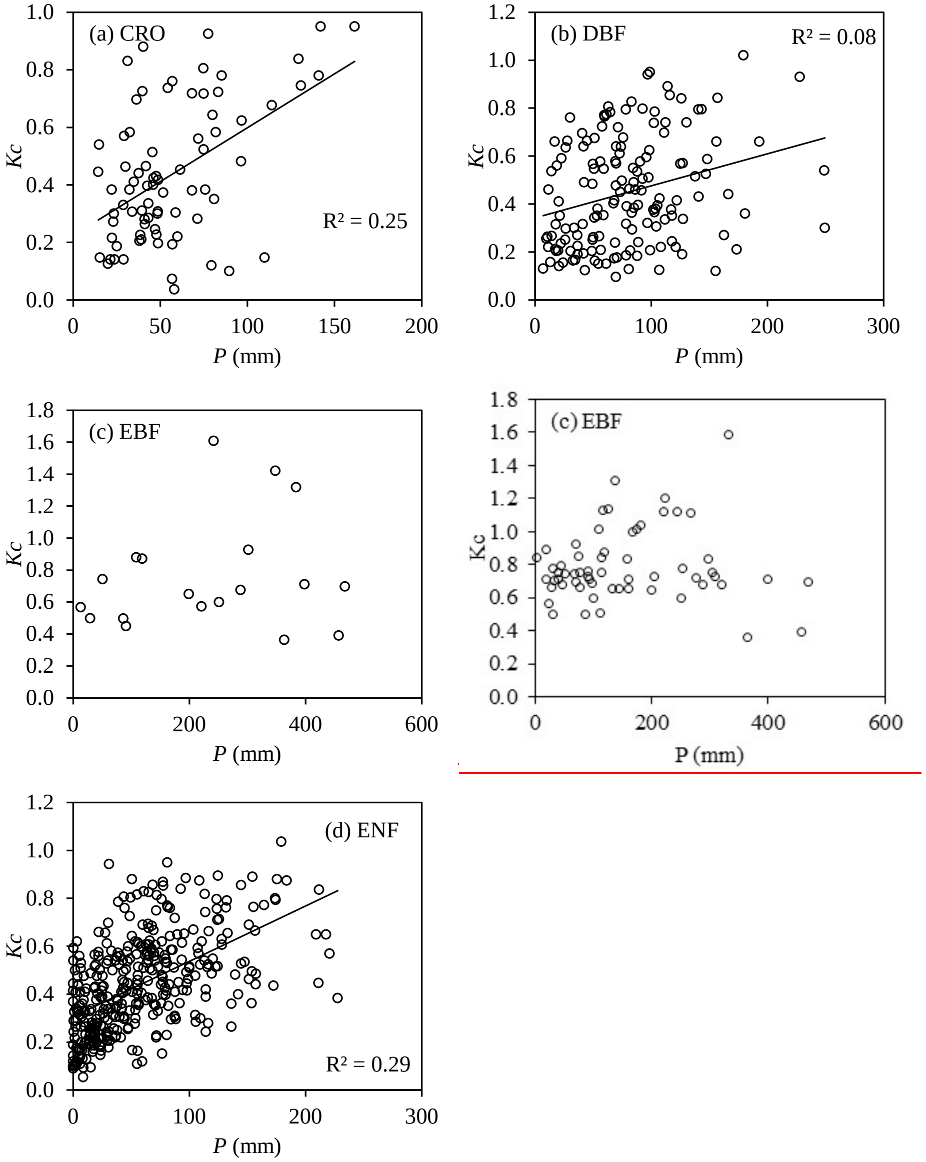
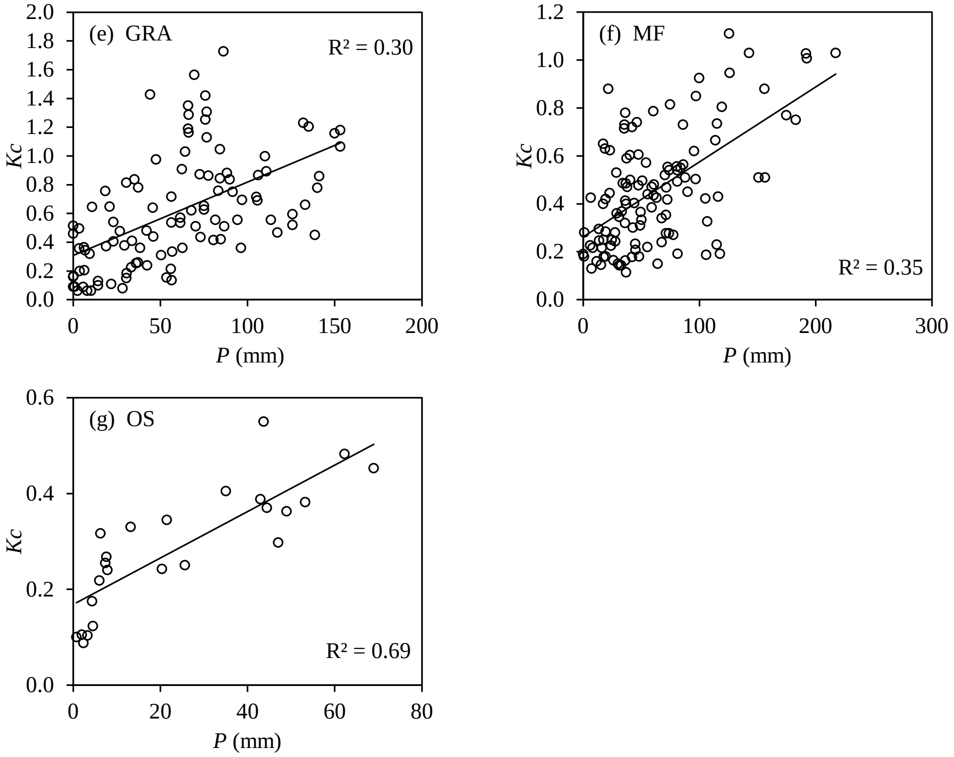

(a) CRO
R² = 0.25
Kc
P (mm)
0.0
0.2
0.4
0.6
0.8
1.0
0
50
100
150
200
(b) DBF
R² = 0.08
Kc
P (mm)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
0
100
200
300
(c) EBF
Kc
P (mm)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
0
200
400
600
(c) EBF
Kc
P (mm)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
0
200
400
600
(d) ENF
R² = 0.29
Kc
P (mm)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
0
100
200
300



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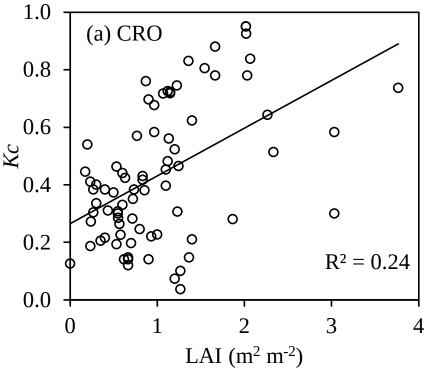

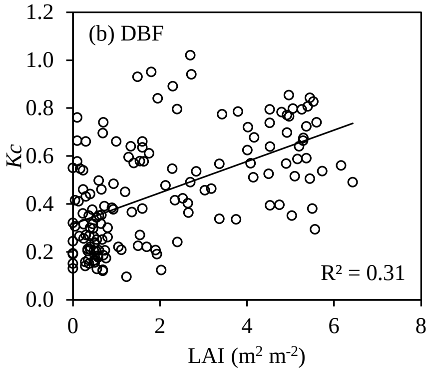

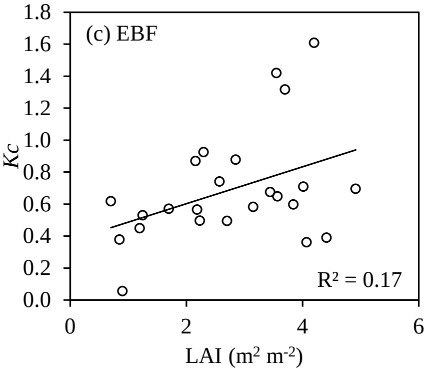

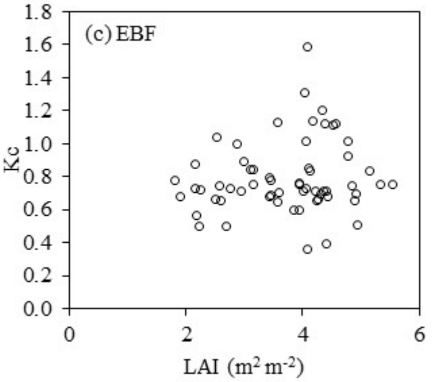

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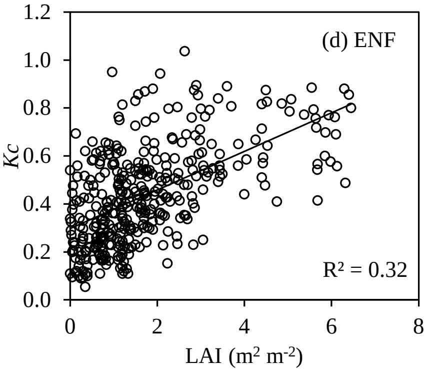

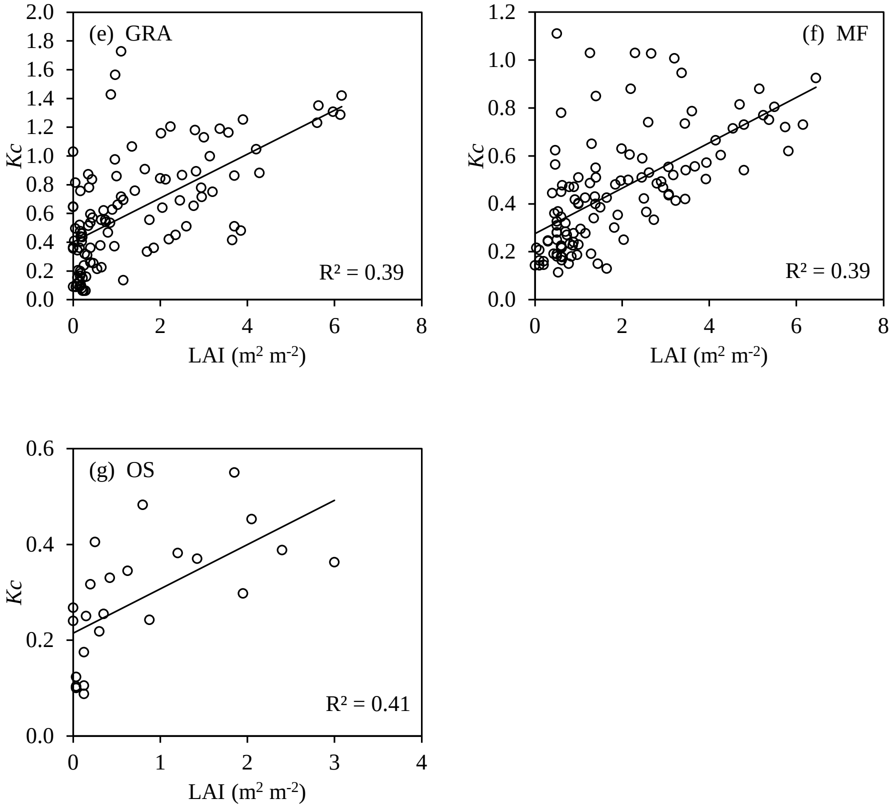

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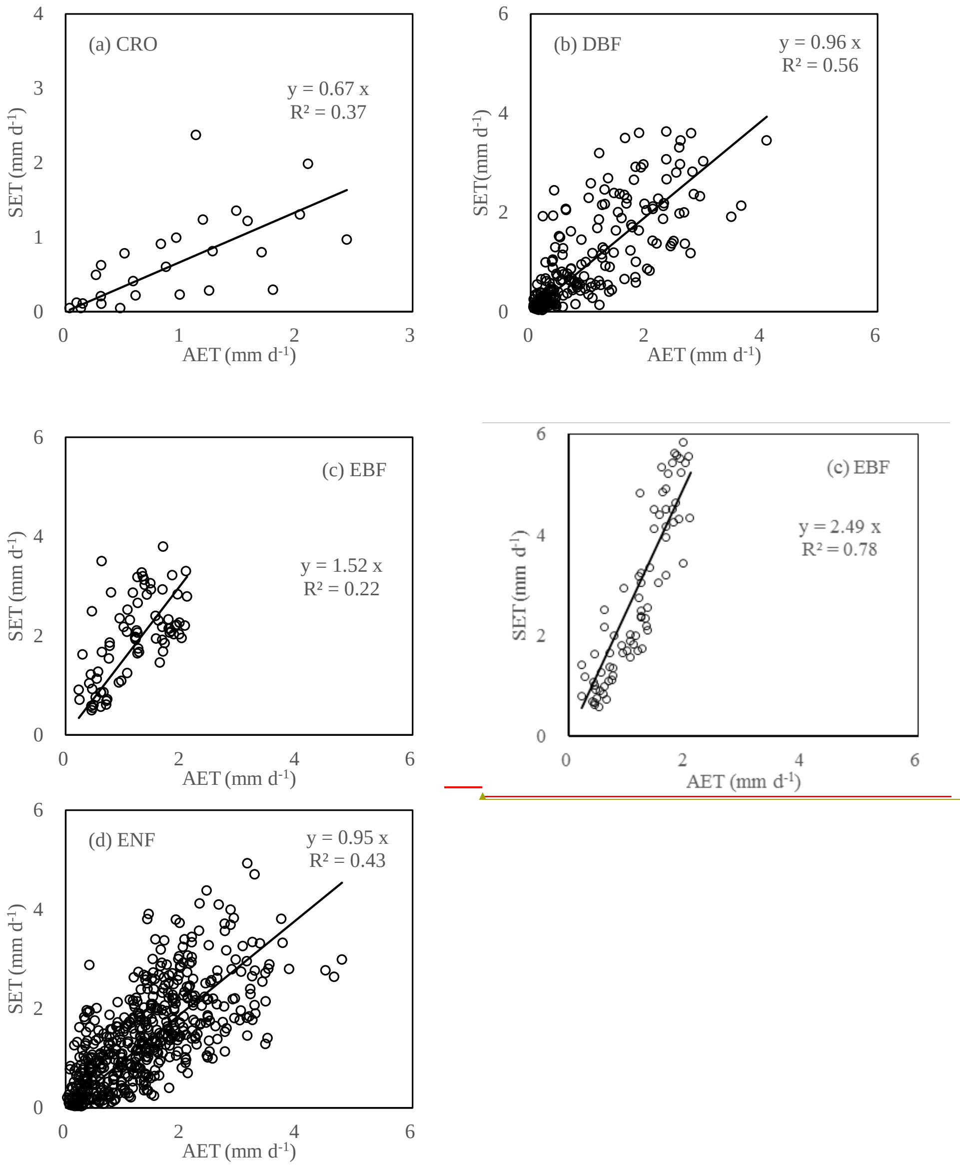

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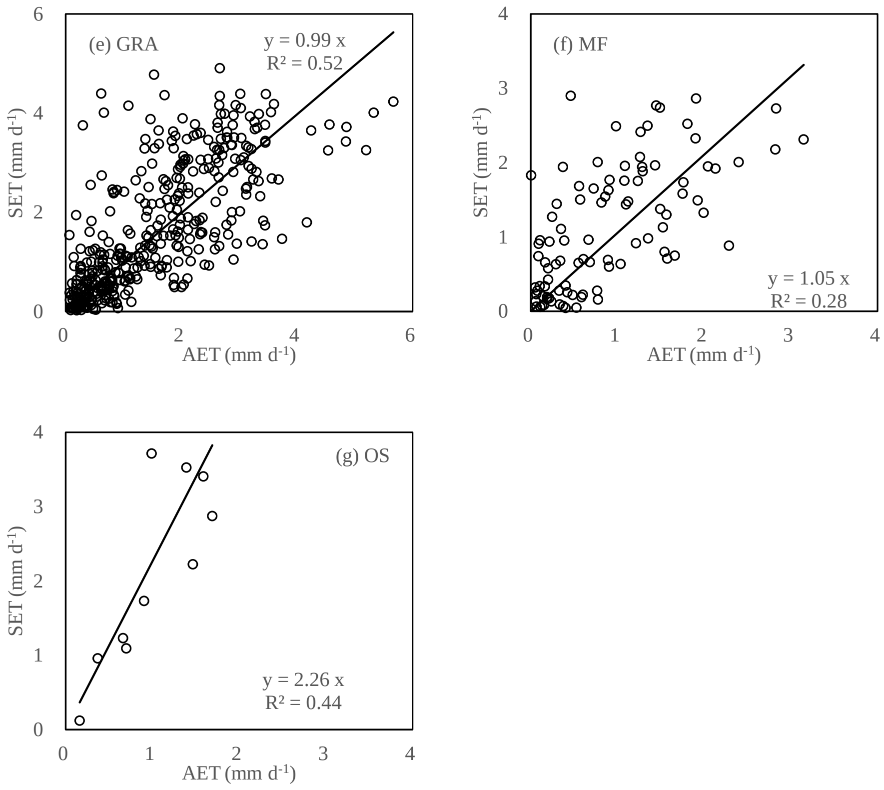

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