Final response to the reviewers comment from Anonymous Referee #1 on the manuscript bg-2020-171: "Evapotranspiration over agroforestry sites in Germany"

We thank you for your feedback, suggestions and helpful comments on the manuscript. In the current document we give a point-by-point answer on above referee report.
We show first the referee comments **(RC)** and second the authors answer **(AR)**. Specific changes in the revised manuscript are marked as green text as part of the authors response.

0. RC: *This paper presents ET measurements from paired monoculture/agro-forestry sites throughout Germany. The results indicate insignificant differences in ET between the land use types, which appears to be a positive result. The writing is adequate, but I personally feel that the document overemphasizes the statistical comparison between the paired sites to the extent that the important message of the paper is obscured. The content of the paper is fine, but the text needs further refinement.*

0. AR: Thank for very much for your positive feedback and the detailed and valuable comments. We reduced discussions on the statistical significance of the differences between ET from the different land-uses both in Abstract as well as in the main text. We are confident that the quality of the manuscript will improve after considering your suggestions.

1. RC: *Page 1 line 23: Direct comparison of ET between wet and dry years is not very relevant because the available energy is likely different between the two years.*

1. AR: We used this comparison to test if we can detect the effect of a wet and a dry year on ET fluxes with the used methods. With this analysis we showed that both methods (ECEB and EC-LC) were suitable to detect differences in ET due to different ambient conditions. But, we also showed that differences in ET between the two land-uses and between the two methods were of similar magnitude and of the same sign (ET_AF > ET_MC; ET_ECEB>ET_EC-LC). This makes it difficult to decide whether differences in ET between AF and MC are caused by the presence of the trees of the AF system, or if the differences are an effect of the methodological uncertainties. We clarified this in the abstract, as also shown in the **2**. **AR** below.

The aforementioned discussions refer to Figure 10 of the initially submitted manuscript. We added a second figure next to the existing one and zoomed into the centre of the plot to indicate the trends. In addition, we used the radiative dryness index on the x-axis instead of the ratio between potential ET and precipitation. The different approaches for potential ET resulted in large differences of up to 100 mm a^{-1}. See the new figure with the extended caption below:

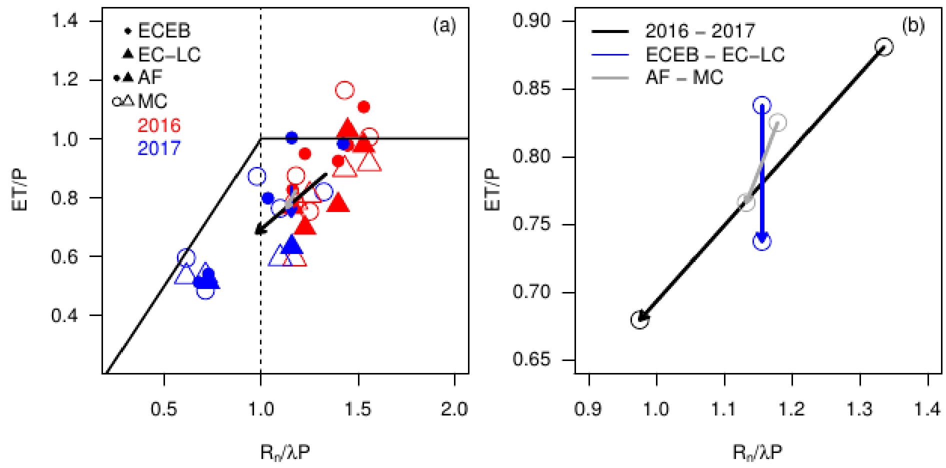

Figure 11. (a) Evapotranspiration index (ET/P) versus the radiative dryness index ($R_n/\lambda P$) for both land-uses (AF: filled triangles and dots; MC: empty triangles and dots), both set-ups (ECEB: dots; EC-LC: triangles) and both years (2016: red; 2017: blue). The bold black line describe regions of an energy limitation ($R_n/\lambda P<1$) and a water limitation ($R_n/\lambda P>1$). The arrows indicate mean trends of ET for the effect of different years (black arrow), different methods (blue arrow) and different land-uses (grey arrow). **(b)** Trends of the mean evapotranspiration index (ET/P) versus the mean radiative dryness index ($R_n/\lambda P$) for the effect of different years (black), different methods (blue) and different land-uses (grey) extracted from figure (a).

2. RC: *Page 1 lines 16-26: This is the most important point of the paper. However your description does not speculate or give guidance as to whether you expect higher ET at the AF or MC locations, no hypothesis.*

2. AR: → we formulated the main objective of this work in the first paragraph of the abstract (Page 1 line 5-6), which was to assess if AF systems have higher ET compared to monoculture systems

We clarified the hypothesis and the objective in the abstract as: "[...] Therefore we hypothesize that short rotation coppice agroforestry systems have higher water losses to the atmosphere via ET, compared to monoculture agriculture without trees. In order to test the hypothesis the main objective was to measure actual evapotranspiration of five AF systems in Germany and compare those to five monoculture systems in close vicinity to the AF systems.[...]"

In addition, we extended the discussion in the abstract in the particular lines with a more precise conclusion:

"With respect to the annual sums of ET over AF and MC, we observed small differences between the two land-uses. We interpret this as an effect of compensating small-scale differences in ET next to and in between the tree strips for ET measurements on system-scale. Most likely, differences in ET rates next to and in between the tree strips are of the same order of magnitude but of opposite sign and compensate each other throughout the year. Differences between annual sums of ET from the two methods were of the same order of magnitude as differences between the two land-uses. Compared to the effect of land-use and different methods on ET, we found larger mean evapotranspiration indices ($\sum$ET/$\sum$P) across sites for a drier than normal year (2016) compared to a wet year (2017). This indicates that we were able to detect differences in ET due to different ambient conditions with the applied methods, rather than the potentially small effect of AF on ET.

We conclude that agroforestry has not resulted in an increased water loss to the atmosphere indicating that agroforestry in Germany can be a land-use alternative to monoculture agriculture without trees.”

3. RC: *Page 2 line 8: You note that SRC are comparable to monoculture (forestry) but you don’t indicate what aspects are comparable - are you refering to energy partitioning and water use?*

3. AR: we refer to the geometrical structure of those systems, rather than energy partitioning or water use; SRCs are not mixed systems like agroforestry (trees and crops), they consist only of one tree species, which is similar to monoculture systems with only one crop species, we changed it in the text as follows:

“SRC plantations are monoculture systems with a single tree species grown.”

4. RC: *Page 2 Intro: Most of your references are relatively recent, you might gain some insights by reviewing earlier work. See references in Cleugh.*

4. AR: We looked through older literature, in particular the review from *Cleugh 1998*, and added the idea of a potential increase of evaporation/transpiration in the quiet zone, when dry air advection is missing, the soil water supply limited and the wind velocity reduced. This process again refers to the area next to the tree strips and how those small-scale effects can be referred to system-scale ET remains unclear.

5. RC: *Page 3 line 10: The ECEB method is not really limited by closure of the energy budget because this is the default assumption for ECEB. It is, however, limited by the accuracy of your estimates of senible heat flux, net radiation, soil heat flux and change in storage terms.*

5. AC: indeed, we changed this as follows:

“The ECEB method is limited by the accuracy of the energy balance components (the net radiation, the sensible heat flux, the ground heat flux and storage terms), typically leading to an overestimation of latent heat fluxes.”

6. RC: *Page 3 line 20: Why do your partition the residual energy budget between just H and LE and not between H,LE and G - or possibly even Rn*

6. AC: Despite substantial research into the partitioning of the energy balance residual (*i.e. Mauder et al. (2017): 'Evaluation of energy balance closure adjustment methods by independent evapotranspiration estimates from lysimeters and hydrological simulations'*) there is no general consensus how to partition the energy balance residual, and the partitioning is likely site and case specific and would require additional information beyond the typical set of measurements we had available. However, research (*Foken et al. (2008): Micrometeorology*) seems to suggest that the largest fraction of the residual is related to the turbulent fluxes (H + LE), rather than to the measurement of available energy. Therefore, we partition the residual only to LE and H.

7. RC: *Page 3 line 21: I would suggest being more specific in your hypothesis. Specify short-rotation copice agro-foresty, as your results may not extent to other systems.*

7. AC: we changed the hypothesis in the introduction and added the hypothesis to the Abstract as well as a related objective:

"The main hypothesis of the current work was that short-rotation coppice agroforestry systems have higher water losses to the atmosphere via ET, compared to monoculture agriculture without trees."

8. RC: *Page 5 line 4: How did you know if precipitation data were missing?*

8. AC: we sampled the meteorological data every 10 seconds; for our analysis we checked how many 10 second values per day were available and compared those to the theoretical number → 10 sec values available/10 sec values theoretical

9. RC: *Page 5 line 10: Did you use the precipitation data from the AF plots? and if so how did you use them?*

9. AC: we did not use the precipitation data from the AF, as the data were strongly affected by interception and not really representative for the AF system, as the precipitation in between the tree strips is expected to be higher than within the tree strips, we used only precipitation from the monoculture system; the annual sums in precipitation between AF and MC differed substantially (AF<<MC), which would have affected the ratios between ET and P. We used only precipitation from the MC sites under the assumption that the mean annual sum of precipitation between AF and MC do not differ due to the small size of the agroforestry systems and no small scale effects on precipitation formation. We added further explanations in the text:

"[...]Therefore, we used the precipitation measurements from the MC system to compute ratios of annually summed actual and potential ET to precipitation at both AF and MC systems. We assume that the annual sum of precipitation at the AF and the MC systems do not differ, due to the relatively small size of the agroforestry systems and no expected local effects of the agroforestry systems on the precipitation formation.[...]"

10. RC: *Page 7 equ 4: Technically, this conversion gives you units of mg/m2 not mm/30 min. (assuming your lambda value is using milligrams and not the more usual grams. This needs to be explicit to avoid readers from incorrectly applying this equation. (i.e. give units for your variables)*

10. AC: we corrected the formula as shown below:

Half-hourly evapotranspiration rates in units of $\mathrm{mm\,30\,min^{-1}}$ were calculated from LE as

$$ET = \frac{LE_{ECEB}(\mathrm{J\,kg^{-1}\,s^{-1}})}{L(\mathrm{J\,kg^{-1}})} \cdot 1800(\mathrm{s\,30min^{-1}}) \cdot \frac{1}{\rho_{H_2O}}(\mathrm{m^3\,kg^{-1}}) \cdot 1000\,\mathrm{mm\,m^{-1}} \quad (4)$$

with L ($\mathrm{J\,kg^{-1}}$) the latent heat of vaporization (Dake, 1972) depending on air temperature T (°C)

$$L = (2.501 - 0.00237T) \cdot 10^6, \quad (5)$$

and $\rho_{\mathrm{H_2O}} = 1000\,\mathrm{kg\,m^{-3}}$ the density of liquid water.

11. RC: *Page 8 line 9-10: This sentence needs to be fixed. Also, it is an assumption that lack of energy budget closure reduces ET. That assumption is not necessarily true.*

11. AC: we reformulated the sentence:

"[...] We corrected \unit{ET_{ECEB}} for the average energy balance non-closure, which we estimated from direct LE measurements by EC during measurement campaigns of minimum four weeks duration. In the current study we found that considering the energy balance residual reduces \unit{ET_{ECEB}}. [...] "

12. RC: *Page 10 line 2: Your Big-Leaf assumption may be appropriate for the MC sites but less so for the AF sites, can you address the potential effects.*

12. AC: The big-leaf assumption might be violated over AF due to the heterogeneity of the system, this could potentially be a problem. In this discussion heterogeneity refers to the different plant species (crops/grasses and trees) of different heights. The trees infer a shaded area in terms of wind and incident radiation in the quiet zone. On the one hand the reduction in incident radiation might lead to reduced ET due to a different leaf stomata regulation from sunlit and shaded leafs both from trees and crops as well as due to reduced wind velocities. On the other hand trees and crops in the windward site are affected by increased wind velocities and varying incident radiation. So, the big-leaf assumption might even be valid over agroforestry systems due to the compensation of the effects in the lee and at the windward site of the tree strips.
Therefore, the canopy resistance derived from meteorological measurements at our flux tower (one flux tower over AF and MC, respectively) might still be representative for the agroforestry system, as the mean meteorological conditions are recorded. We added some more explanations+discussions in the Mats+Methods section 2.6 ("Canopy resistance") of the revised manuscript:

"Effects of structural differences between AF and MC on ET were studied in terms of the relationship between the aerodynamic and canopy resistances (\unit{s\,m^{-1}}) and half-hourly ET. The canopy resistance was calculated from the rearranged Penman-Monteith equation (Eq. (\ref{equ:PM_equ})) for evapotranspiration, which depends on the canopy conductance, g_c

(\unit{m\, s^{-1}}), and the aerodynamic conductance for heat, g_{ah} (\unit{m\, s^{-1}}). The canopy conductance follows the big leaf assumption, assuming that the whole canopy response to environmental changes equals the response of a single leaf. This assumption is valid for the monoculture system with a single crop type of similar height. For the agroforestry systems this assumption is violated due to the different plant species (trees and crops) of different heights. In the lee of the tree strips the reduced wind speed and incident radiation might lead to reduced ET due to a different leaf stomata regulation of sunlit and shaded leafs. In the windward site of the tree strips trees and crops are affected by increased wind velocities and varying incident radiation, thus opposite conditions compared to the lee of the tree strips. However, we assume that the meteorological data from our flux tower represent the mean state of the meteorological conditions within the agroforestry system. Therefore, we are confident that the big-leaf assumption is also valid for agroforestry systems."

13. RC: *Page 10 Equ 11: Here and elsewhere in the paper you use 'lambda' as the latent heat of vaporization but in the text you use 'L'. Best to use one or the other, not both.*

13. AC: we changed it from 'lambda' to L

14. RC: *Page 10 line 9: is 'ppp' a variable, if so it should be shortened to a single character.*

14. AC: we changed it from ppp to P_A

15. RC: *Page 10, equ 14: don't use VPD as a variable name, reduce it to a single character (e.g. 'D', or a single character variable with a subscript or superscript (e.g. 'e_D')*

15. AC: we changed VPD to D

16. RC: *Page 11 line 2-3: Did you account for wind direction. The AF site is inherently non-homogeneous, and similar to other row-structured crops may have strong directional dependencies.*

16. AC: no, we neither account for any wind direction, nor will we include a new analysis

17. RC: *Page 11 sec 3.1: This information might be more succinctly incorporated as a table - only referring in text to any atypical conditions.*

17. AC: we kept this section and shortened it; we added Table A2 to this section as follows:

3.1 Meteorological conditions and plant physiological stages during the campaigns

For the meteorological conditions during the campaigns we refer to time series of relevant meteorological parameter in Figure 2 and mean values in Table 3.

Table 3. Mean air temperature, T_A, vapor pressure deficit, D, global radiation, R_G, and the cumulative precipitation, P, for the respective site and campaign period.

Site	T_A (°C)	P (mm)	D (hPa)	R_G (Wm^{-2})
Dornburg AF	19.0	57.1	6.41	200.7
Dornburg MC	18.6	2.1	7.35	212.6
Forst AF	21.4	18.9	12.02	358.8
Forst MC	21.2	14.8	11.88	371.5
Mariensee AF	18.54	40.6	6.2	258.9
Mariensee MC	16.93	163.5	4.7	172.8
Reiffenhausen AF	19.31	26.3	8.02	219.1
Wendhausen AF	16.6	48.6	5.4	235.0
Wendhausen MC	15.5	90.7	5.2	239.9

18. RC: *Page 14 line 24-25: Water vapour concentrations are not a good indicator of spectral response - many other factors come into play.*

18. AC: We changed the text to reflect that the spectral response characteristics of the two analyser were similar as follows:

"[...] fluctuations were attenuated. The spectral response characteristics of the gas analyser and the thermohygrometer set-up were similar. Therefore, the correction of high-frequency losses is expected to be higher for the compromised gas analyser at the respective MC systems, than for a fully functional gas analyser."

19. RC: *Page 15 fig 4: Why is there no nocturnal data for some sites?*

19. AC: There was not enough power available to cover the power needs, due to the solar power supply of the station. Therefore, we had larger data losses during night. We included an explanation to the figure:

"Gaps in nocturnal data are due to the limited power availability from the solar power supply."

20. RC: *Page 17 sec 3.4: Instead of using "LE from EC", "LE from EC_LC", "LE from ECEB", might I suggest using subscripts LE_a = LE from EC LE_b = LE from ECEB LE_c = LE from EC_LC It will make reading the paper much easier.*

20. AC: it is a good suggestion, we changed the text as follows

LE_{ECEB}, LE_{EC} and $LE_{EC\text{-}LC}$ for LE and
ET_{ECEB}, ET_{EC} and $ET_{EC\text{-}LC}$ for ET

21. RC: *Page 20 line 6-14: This is really interesting. I would cut down on the amount of stats provided and focus on the underlying concepts of what be causing this - which obviously is on scales much bigger than the individual sites*

21. AC: Indeed, we discussed partly in the manuscript that circulations bigger than the individual sites might cause the observed pattern. If this is really the case, we would require additional information beyond the typical set of measurements we had available. Therefore, we did as suggested and cut down the amount of statistics.

"[...]Interestingly, the diel pattern of the EBR from \unit{LE_{EC}} at both land-uses at all sites are equal. Additionally, the differences between the median diel cycle EBRs (between 6 am and 6 pm) at the AF and the MC system were small, with differences of minimum -0.09 and maximum 0.13 across sites. As both flux towers located at the AF and the MC system at one site are separated by approximately 100 to 500 m and the diel patterns look similar, we suspect that the non-closed surface energy balance at one site is caused by local effects of longer wavelength than the commonly applied averaging period of 30 minutes and beyond the individual site level.[...]"

Additionally, we added a figure with median diurnal cycles of the different energy balance components for the Dornburg AF and MC sites to explain the unexpected diel cycle of the energy balance ratio at the sites. We added some more text to strengthen our interpretation of an advection effect on the observed energy balance ratio.

Here the new figure:

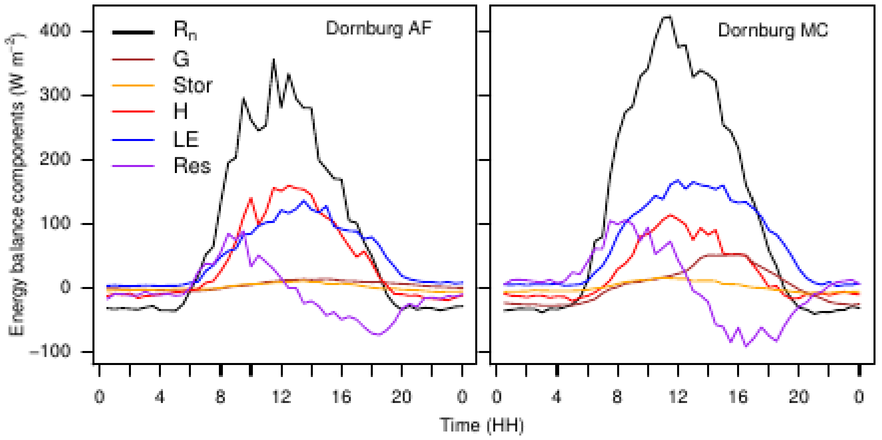

Figure 7. Median diurnal cycle of the energy balance components for Dornburg AF and MC for the campaign times (Table A1).

And here the extended text:

The Dornburg site might be affected by horizontal advection of moisture and heat. Oncley et al. (2007) reported that the advection of moisture had the highest contribution to the unclosed energy balance compared to the other components and the maximum peak of the horizontal moisture advection term was in the afternoon, as energy was accumulated during the day and released in the afternoon. We suspect that this is also the case for the Dornburg site. The sensible heat flux follows the diurnal cycle of available energy with the maximum peak at midday at the agroforestry and the monoculture system (Fig. 7). In contrast, the median of the latent heat flux had its maximum in the afternoon at around 2 pm and was positive even after the available energy changed its sign.

In addition to advective transport, the unclosed surface energy balance could be related to energy storage terms such as biomass, the air or photosynthesis (Jacobs et al., 2008), that have previously not been considered. The pattern seen at Dornburg may be attributed to a release of energy during the afternoon, which correspond to a surplus of energy and a better closure of the energy balance. In the morning hours the storage terms have an opposite sign, which correspond to a lack of energy and a subsequent poorer energy balance closure. Considering the storage terms would lead to a reduction of the residual energy and a better closure of the energy balance.

22. RC: *Page 20 line 17-18: This seems inconsistent with your preceding paragraph.*

22. AC: indeed, we removed the discussion on the residual energy, as this is causing the diel cycle of the energy balance ratio, which we explained

23. RC: *Page 20 sec 3.4.3: Not so sure about the usefulness of this section. As presented it is a simple algebraic exploration assuming linear relationships. In reality, changing one or more the components by +/- 20% may have non-linear effects on the other components, which can not be accurately captured by the your current analysis method.*

23. AC: We removed this section from the paper

24. RC: *Page 22 line 15: This is perhaps expected, by definition Rn is the sum of the other components.*

24. AC: Yes, this is correct. We removed this section from the paper.

25. RC: *Page 22 line 27-30: Is it correct that this is an assumption and you did not measure evaporation and transpiration separately.*

25. AC: yes, this is an assumption and we changed it accordingly:

"We assume that after the ripening of the crops evaporation contributed the most to the measured ET at the MC plot, whereas at the AF plot both evaporation from the crop fields between the tree strips and transpiration from the trees contributed to the measured flux."

26. RC: *Page 24 sec 3.5.2: Even though ET was measured by EC only for campaigns, it might be useful to compare sums of ET by all three methods for those campaign periods.*

26. AC: we included a new sub-section 3.5.1 'Sums of evapotranspiration during the campaigns' and a figure:

3.5.1 Sums of evapotranspiration during the campaigns

Sums of evapotranspiration for all three methods, all sites and the campaign periods indicate higher sums of $\mathrm{ET_{ECEB}}$ relative to $\mathrm{ET_{EC}}$, except for Dornburg AF (Fig. 8). The difference between sums of $\mathrm{ET_{ECEB}}$ and $\mathrm{ET_{EC}}$ reflect the unaccounted correction of $\mathrm{ET_{EC}}$ and $\mathrm{ET_{ECEB}}$ for the energy balance non-closure. The large difference between sums of

$\mathrm{ET_{ECEB}}$ and $\mathrm{ET_{EC}}$ at Mariensee AF correspond to the low energy balance closure of 65% at the site. Differences between sums of $\mathrm{ET_{EC-LC}}$ and $\mathrm{ET_{EC}}$ correspond to lower $\mathrm{ET_{EC-LC}}$ than $\mathrm{ET_{EC}}$ over the AF systems and higher $\mathrm{ET_{EC-LC}}$ than $\mathrm{ET_{EC}}$ over the MC systems. This is indicated by slopes smaller and higher one of a linear regression analysis between $\mathrm{ET_{EC-LC}}$ and $\mathrm{ET_{EC}}$ (Table 4).

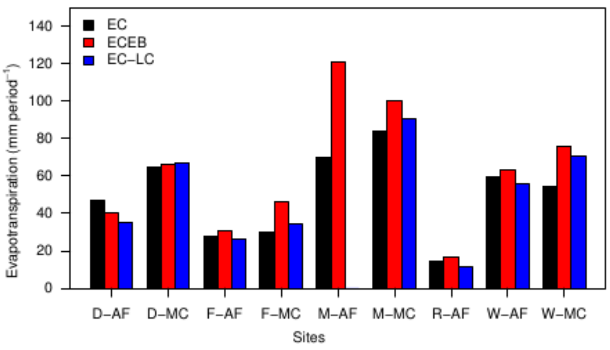

Figure 8. Sums of uncorrected and not gap-filled half-hourly evapotranspiration for all three methods and all sites during the campaign periods. Sites are abbreviated by their first letter and contain either AF for agroforestry or MC for monoculture. Incomplete records with either ET_{EC}, ET_{ECEB} or ET_{EC-LC} missing were omitted. Data for ET_{EC-LC} at Mariensee AF are missing due to technical problems of the sensor during the campaign and all data for Reiffenhausen MC are missing due to the unavailability of a campaign.

27. RC: *Page 27 line 3: how do you get a displacement height of 7 m with a canopy height of 5 m?*

27. AC: yes, this is a typo and we changed it in the text to:

“[...] a displacement height d of 0.7 m and 3.5 m for canopy heights of 1 m and 5 m, respectively.”

28. RC: *Page 27 line 7-8,13-14: Is these relationship inherent from the derivation of canopy conductance from ET?*

28. AC: The canopy resistance was derived as the inverse of the canopy conductance with $ET_{EC-LC.}$ Small differences in canopy resistance between the two land-uses are an artefact from small differences in ET between the two land-uses. We did change the title of the derivation of r_c and r_ah from ‘Canopy conductance’ to ‘Canopy resistance’ to make this more clear. Additionally, we moved the whole derivation of the canopy resistance and other formulas to the Appendix to keep the overall length of the manuscript short.

Final response to the reviewers comment from Anonymous Referee #2 on the manuscript bg-2020-171: "Evapotranspiration over agroforestry sites in Germany"

We thank you for your detailed feedback, suggestions and helpful comments on the manuscript. In the current document we give a point-by-point answer on above referee report. We show first the referee comments **(RC)** and second the authors answer **(AR)**. Specific changes in the revised manuscript are marked as green text as part of the authors response.

1. RC: *The authors measured evapotranspiration (ET) over pairs of adjacent agroforestry (AF, tree lines plus crop or grassland) and tree-free reference fields (MC for monoculture, only crop or grassland) at five sites in Germany over up to 2 years with 3 different methods. Plain eddy-covariance (EC) was used during campaigns, roving between sites due to limited gas analyzer availability. An energy balance method (ECEB) yielding ET as residual of EC measurements of the sensible heat flux and the non-turbulent energy balance terms, as well as a low-cost (EC_LC) method introduced elsewhere by the authors were operated continuously over the 2-year period and validated against EC. The paper presents - a comparison of the methods, in particular of the continuous methods versus EC - a detailed analysis of the energy balance closure (EBC) problem for the concerned methods (EC and EC-LC), and - a comparison of ET between AF and MC, between sites and years, and possible explanations on the result of this comparison, in particular on AF vs. MC The study presents the results of an impressive amount of work, applied according to best practice and including innovative elements, to questions relevant to BG and helpful for land use management decisions. The paper is well written and in terms of content and methods integrity could be published as is. However, the choice of the authors to treat so many dimensions (5 sites with 2 plots each, 3 methods, 3 above research questions) in one paper, makes the clear presentation of methodology and results a particular challenge. In this respect the readability of the mansucript could be improved in several ways. As far as I am concerned, all these improvements are optional; implementing some of them would qualify as minor revision and probably describes my recommendation best.*

1. AR: Thank for very much for your positive feedback and the detailed and valuable comments. We are confident that the quality of the manuscript will improve after considering your suggestions.

2. RC: *1. Whereas the abstract doesn't specify on the nature of the "monoculture" (MC) and the start of the introduction explicitly (and correctly) states that tree plantations can be monocultures as well, it becomes clear only later (maybe only in section 2.1 if I didn't overlook anything) that MC in this study refers exclusively to the crops/grass without trees (as opposed to a dense tree monoculture without a deliberately cropped understorey, which could be just an as relevant and logical comparison partner). Maybe it would be better to replace MC by something like e.g. NT for no-tree. If not I suggest to clarify earlier what MC in this paper means.*

2. AR: We prefer the current abbreviation of AF and MC. We clarified in the abstract and the main text what exactly the two abbreviations refer to.

In the Abstract:
"Therefore we hypothesize that short-rotation coppice agroforestry systems have higher water losses to the atmosphere via ET, compared to monoculture agriculture without trees (MC)."

In the introduction:
"The cultivation of fast growing trees with annual crops or perennial grass-lands on the same piece of land is an example of agroforestry (AF) \citep{Morhart2014,Smith2013} and has numerous environmental benefits relative to monoculture (MC) systems consisting only of crops or grasses without trees \citep{Quinkenstein2009}."

3. RC: *2. The fact that the authors seem to have tried (if I didn't misunderstand) both, down-correcting EBEC results to yield ET estimates with an EBC gap (sect 2.3.1, p8L17) and sometimes up-correcting EC and EC-LC results (Eq. 7-9, table 5), makes it hard to follow the interpretation of the results, particularly in places where the authors try to explain differences between methods / fields with their different EBCs (p14L32 / Sect. 3.3). Ideally it should be stated somewhere clearly that you present all results with (then down-correcting ECEB) or without (then up-correcting EC and EC-LC) an anergy balance closure gap. If then having to do the opposite, or a halfway correction, is still urgently needed for particular tasks in particular places, such as e.g. gap-filling between ECEB and EC-LC, it should be made clear at these points that this is the only purpose and usage of that "other" correction approach.*

3. AR: We treated the data in two different ways:
→ 1. we neither corrected the data up or down for the methodological comparison of the different methods based on the campaigns to explain potential differences between methods, as well as for the energy balance closure estimation (p15 Fig.4, p16 Table 3, p18 Fig. 5, p19 Table 4, p21 Fig. 6 of the initially submitted manuscript)
→ 2. for the comparison of annual sums of ET we did the 'half-way correction' of ET_{ECEB} (down-corrected, both for gap-filling of ET_{EC-LC} and ET_{ECEB}) and ET_{EC-LC} (up-corrected) to get closer to reality (as explained in Section 2.3 of the initially submitted manuscript) (p24 Fig. 8, p26 Fig. 9, p27 Tab. 5, p28 Fig. 10 of the initially submitted manuscript)

We included a short explanation on the different gap-filling and energy balance closure adjustment procedures in Section 2.3 of the revised manuscript (“Gap-filling and energy balance closure adjustment”), as shown below:

2.3 Gap-filling and energy balance closure adjustment

For the comparison of ET_{EC}, ET_{ECEB} and ET_{EC-LC} and the estimation of the energy balance closure during the campaigns, we neither gap-filled the data, nor corrected the data for the energy balance non-closure. For the calculation of annual sums of ET_{ECEB} and ET_{EC-LC} data gaps were filled, and corrected for the energy balance non-closure by distributing the residual equally to H and LE. The residual was estimated by machine learning for times when no data were available. In the following subsections we describe the gap-filling and energy balance closure adjustment procedures for the ECEB and EC-LC set-ups in more detail.

We removed the uncorrected annual sums in Table 5 (initially submitted manuscript) as shown below in the new table (now table No 6 in the revised version of the manuscript), as we never used the information of the uncorrected annual sums of ET_ECEB in the text:

Table 6. Annual sums of energy balance closure corrected actual evapotranspiration, ET ($mm\,a^{-1}$), and precipitation, P ($mm\,a^{-1}$) for all sites, both set-ups (ECEB and EC-LC) and both years (2016 from April to December, and 2017 from January to December). The annual sums of ET_{ECEB} and precipitation at Reiffenhausen AF and MC in 2017 contain data from 01 January 2017 to 01 July 2017 due to destruction of the station. Annual sums of ET_{EC-LC} for Dornburg AF and MC, Mariensee AF, Reiffenhausen AF and MC in 2017 are missing due to instrument malfunctions.

Method	ECEB		EC-LC			
Sites	ET 2016	ET 2017	ET 2016	ET 2017	P 2016	P 2017
Dornburg AF	383	500	321	–	414	626
Dornburg MC	362	546	325	–	414	626
Forst AF	494	540	363	340	520	538
Forst MC	409	411	309	320	520	538
Mariensee AF	386	389	405	–	394	757
Mariensee MC	459	451	354	404	394	757
Reiffenhausen AF	406	252	358	–	366	256
Reiffenhausen MC	368	210	336	–	366	256
Wendhausen AF	410	446	380	424	496	822
Wendhausen MC	373	400	401	440	496	822

4. RC: *3. In many figures an important correspondence between sub-panels (e.g. a-e) and cases (mostly sites, sometimes methods or periods) can only be established through the caption, which is even complicated by the letters changing their meaning with respect to site depending on whether one or two sub-panels are needed per site. I suggest to include the most important differences (e.g. site names) in the subpanels or next to rows or panels of subpanels, such that the figure can better stand alone. In Figure 9 quite suddenly abbreviations for the site names are introcudes which were nowhere used before (but might be useful for the above suggestion). It might also be worth thinking about re-naming the sites by characteristics relevant to the interpretation, e.g. crop vs. grass and/or the ranking of tree density.*

4. AR: we did as suggested and included following abbreviations in following figures in the revised version of the submitted manuscript:
Figure 1: instead of (a), (c), (e), (g), (i) we wrote Dornburg, Forst, Mariensee, Reiffenhausen, Wendhausen; we remove the letters from the aerial photograph
Figure 2: we replaced (a) by Dornburg MC, (b) by Dornburg AF, (c) by Reiffenhausen AF, (d) by Wendhausen, (e) by Forst, and (f) by Mariensee
Figures 3 and A3: instead of (a)-(e) we wrote Dornburg, Mariensee, Forst, Reiffenhausen and Wendhausen
Figure 4: instead of the letters (a)-(i) we wrote Dornburg AF, Dornburg MC, Forst AF, Forst MC, Mariensee AF, Mariensee MC, Reiffenhausen AF, Wendhausen AF and Wendhausen MC
Figure 5: instead of the letters (a)-(i) we wrote Dornburg AF, Dornburg MC, Forst AF, Forst MC, Mariensee AF, Mariensee MC, Reiffenhausen AF, Wendhausen AF and Wendhausen MC
Figure 6: instead of (a)-(e) we wrote Dornburg, Forst, Mariensee, Reiffenhausen and Wendhausen
Figure 7: Dornburg AF and Dornburg MC
Figure 8: we wrote D-AF, D-MC, F-AF, F-MC, M-AF, M-MC, R-AF, W-AF and W-MC
Figure 9: instead of (a)-(e) we wrote Dornburg, Forst, Mariensee, Reiffenhausen and Wendhausen
Figure 12: instead of (a)-(e) we wrote Dornburg, Forst, Mariensee, Reiffenhausen and Wendhausen
Figure A1: instead of the letters (a)-(i) we wrote Dornburg AF, Dornburg MC, Forst AF, Forst MC, Mariensee AF, Mariensee MC, Reiffenhausen AF, Wendhausen AF and Wendhausen MC
Figure A2: instead of the letters (a)-(h) we wrote Dornburg AF, Dornburg MC, Forst AF, Forst MC, Mariensee MC, Reiffenhausen AF, Wendhausen AF and Wendhausen MC
Figure A4: instead of (a)-(e) we wrote Dornburg, Forst, Mariensee, Reiffenhausen and Wendhausen

5. RC: *4. Textbook knowledge that many others would present not at all or in an appendix is reported in the methods section. This is not necessarily a bad thing (although contributing to the overall length), but currently it is not done consistently. Equation 4 and 5 detail on quite straightforward conversion matters, and equations 12 and 13 on saturation vapour pressure and its slope, but on the other hand section 2.2.3 (p7L26) merely states that "mole fraction was calculated using measurements of relative humidity, air temperature and air pressure...", although this conversion involves at least as many reproduction-relevant decisions (and maybe partly same equation(s)) as the ones mentioned before. Ways out could be e.g. either to drop all these details, or insert an appendix section where such equations are gathered, some of which could then be referred to from multiple points of the paper if necessary.*

5. AR: To keep the main text concise, and given that some of the equations were already described in Markwitz and Siebicke (2019), presenting the EC-LC set-up, we moved Eqs. 4-6 and Eqs. 11-18 to the appendix and included conversion formulas from section 2.2.3. The Appendix is now structured as follows and can be seen in the revised version of the manuscript.

A Derivations
A1 Half-hourly ET rates and soil storage flux
A2 Water vapour mole fraction C_{H2Ov} from the thermohygrometer
A3 Canopy resistance

6. RC: *Further comments on the analysis:*
5. p08L19 (Sect 2.3.1): I may be overlooking something, and given how little we know about the source of the EBC problem your solution might be as good or bad as the more widespread Twine partitioning, but I do not understand why the latter cannot be applied to your data. Mathematically a Bowen-ratio conserving correction is equivalent to correcting both fluxes by the same factor 1/EBR, without any explicit need to know/compute/introduce the Bowen Ratio itself (and even if this was the case there would probably be an analytical or iterative solution to the problem). So if the available H (from EC) is already subject to the closure problem and does not need to be "down-corrected", the only thing left to do is to multiply the residually determined LE with EBR to get the desired estimate of a "non-closing / EC-like" LE.

6. AR: The suggested solution of multiplying LE_ECEB with the EBR is somehow limited by the fact that the EBR from EC was only available for the duration of the measuring campaigns and this would require the prediction of the EBR. Another solution would be to multiply the mean EBR (derived as the slope between H+LE and Rn-G from the campaigns) with the 30-min LE_ECEB. This would be even less accurate due to missing the temporal variability of the EBR throughout the day and the year. As already stated, the main question is not which method to use, it is rather the question how the residual gets partitioned to the different components. From our point of view, the current solution was the only viable option given the current data.

7. RC: *6. p11L05 (Sect. 2.6 / Equation 18): After an elaborate description of how the Penman-Monteith approach is used to infer conductances, the simpler (humidity-free) Priestly-Taylor approach is introduced for the Budyko analysis, although alternatives consistent with Penman-Monteith (e.g. FAO grass reference ET) exist. Was there a particular reason for this decision? Luckily it probably affects all sites similarly (more similar than in a global study mixing very humid and arid sites) and seems only to be needed in Fig. 10, even there only slightly changing X axis position but not the overall pattern.*

7. AR: We compared the results from the different equations for potential evaporation/ET and we found differences in annual sums of up to 100 mm a^{-1}. This seems to be too uncertain and we decided to follow the initial idea of Budyko, who assumed that a sufficient amount of available energy is needed to evaporate precipitation. Therefore, we plotted the relationship between ET/P vs. R_N/LP, with R_N the the annual sum of net radiation. We also added a second figure to the existing one, given only the arrows of mean ET/P and Rn/P for the two land-uses (AF and MC), the two methods (ECEB and EC-LC), and the two years (2016 and 2017). Please find the new figure below:

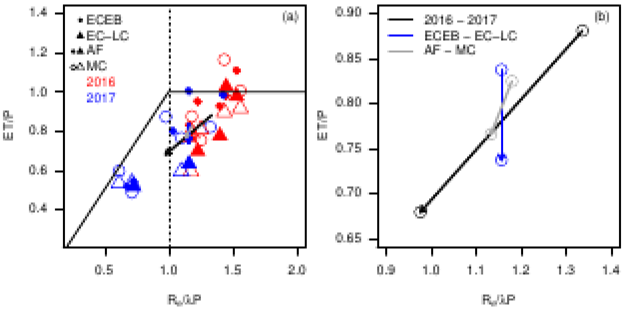

Figure 11. **(a)** Evapotranspiration index (ET/P) versus the radiative dryness index ($R_n/\lambda P$) for both land-uses (AF: filled triangles and dots; MC: empty triangles and dots), both set-ups (ECEB: dots; EC-LC: triangles) and both years (2016: red; 2017: blue). The bold black line describe regions of an energy limitation ($R_n/\lambda P<1$) and a water limitation ($R_n/\lambda P>1$). The arrows indicate mean trends of ET for the effect of different years (black arrow), different methods (blue arrow) and different land-uses (grey arrow). **(b)** Trends of the mean evapotranspiration index (ET/P) versus the mean radiative dryness index ($R_n/\lambda P$) for the effect of different years (black), different methods (blue) and different land-uses (grey) extracted from figure (a).

8. RC: Further comments on technical / presentation details:
7. p01L14 (abstract): Consider rewording "superior performance" to make clear that this indicates superior agreement with the widespread EC method. This is not necessarily identical to superior performance in capturing true ET.

8. AR: We changed this accordingly:

"Root mean square errors of LE_{EC-LC} vs. LE_{EC} were half as small as LE_{ECEB} vs. LE_{EC}, indicating a superior agreement of the EC-LC set-up with the EC set-up compared to the ECEB set-up."

9. RC: *8. p01L17 (abstract): There is an ongoing debate whether, how much and how we should continue to base conclusions about differences on significance (e.g. Amrhein et al., Nature 567:305, DOI: 10.1038/d41586-019-00857-9). While reporting p-values in a paper for the sake of completeness cannot do much harm (without wrong interpretation), care should be taken especially where wrong use in the past was particularly popular, and one of these cases is inferring that a difference is nonexistent or unimportant from a "failed" (insignificant) test. This sentence (and versions of it in the main text) comes somewhat close to suggesting something like this (although not explicitly claiming it). It might be more convincing to show (as done in the main text) how small the difference actually was (maybe compared e.g. to the mean ETs or to the inter-site, inter-period, or inter-method variability that was probably at the bottom of the significance test) and then it could still be mentiond if wanted (here or elsewhere) that the difference was also statistically insignificant (which depends strongly on sample size even if all the means and variances stay the same, and unlike conclusions from significant results, conclusions from insignificant results have the property to become the* *more likely the smaller the sample size). Also note that if keeping reporting the p-values somewhere, they should be rounded to a reasonable number of digits; especially for the second one at L23,* $p = 0.0007$ *or* $p < 0.001$ *would be sufficient.*

9. AR: We removed the p-values and statistics in the Abstract as shown below:

“[...] With respect to the annual sums of ET over AF and MC, we observed small differences between the two land-uses. We interpret this as an effect of compensating small-scale differences in ET next to and in between the tree strips for ET measurements on system-scale. Most likely, differences in ET rates next to and in between the tree strips are of the same order of magnitude but of opposite sign and compensate each other throughout the year. Differences between annual sums of ET from the two methods were of the same order of magnitude as differences between the two land-uses. Compared to the effect of land-use and different methods on ET, we found larger mean evapotranspiration indices ($\sum$ET/$\sum$P) across sites for a drier than normal year (2016) compared to a wet year (2017). This indicates that we were able to detect differences in ET due to different ambient conditions with the applied methods, rather than the potentially small effect of AF on ET.

We conclude that agroforestry has not resulted in an increased water loss to the atmosphere indicating that agroforestry in Germany can be a land-use alternative to monoculture agriculture without trees. ”

10. RC: *9. p02L08 (Sect. 1): "comparable" reads strange in this context. Basically they are, arent't they? As far as I know the term monoculture does not distonguish between agriculture and forestry. Also see comment 1.*

10. AR: Yes, we removed the term “comparable” and rewrote the sentence:

“SRC plantations are monoculture systems with a single tree species grown.”

11. RC: *10. p02L32 (Sect. 1): "such as" reads strange in this context. Maybe ", i.e." instead?*

11. AR: We changed this accordingly:

“For agroforestry systems we formulated the same hypothesis, i.e. system-scale evapotranspiration over agroforestry systems is higher compared to monoculture agriculture without trees.”

12. RC: *11. p03L01 (Sect. 1): depend*s**

12. AR: We changed this accordingly.

13. RC: *12. p03L29 (Sect. 2.1): While reporting the access date of an URL is important if that URL is a source of data/information that couldn't be replaced by a better source, in this case the URL more has the role of an advertisement or a reference to further information for interested readers, and what exactly they will find at the project site if it still exists is not relevant to the paper. For this an access date seems inappropriate. If you weren't asked to add it during the access review, I'd suggest to remove it.*

13. AR: We were asked to include the access date to all the URL's in a previous publication, so we just added it here as well. It seems to be a journal requirement. But, we can change this later, if required.

14. RC: *13. p04L01 (Figure 1): Maybe add a scale bar to the aerial views (or one scale information for all if they are the same). I wonder how wide the elongated MC strip at Forst (b) was, how different the management west and east of it was, and how this is reflected in Sect. 3.2 (footprint analysis).*

14. AR: We added a scale at each of the sites because they are not the same. The strip at Forst MC is 48 m wide and the management at the east and the west of this strip was always the same, but different from the MC strip. The crop type at the MC strip was always the same as in between the tree strips at the agroforestry system. As shown in Fig. 3 the footprint extended beyond the MC strip, hence, fluxes at the MC were also affected by the nearby crop fields.

15. RC: *14. p05L1 (Table 1): System size. Specify if it refers to AF, MC or the sum of both.*

15. AR: The system size referred to the AF system only and we changed it from "System size" to "Agroforestry system size".

16. RC: *15. p05L18 (Sect. 2.2.1): Did I understand correctly that this required at least two available Li-7200? If yes clarify, if no reword sentence.*

16. AR: Yes, we deployed two LI7200 in parallel in 2017. We clarified this:

"During the field campaigns the standard set-up was extended by an enclosed-path infrared gas analyser (LI-7200 , LI-COR Inc., Lincoln, Nebraska, USA). In 2016, the campaigns were conducted separately at the AF and MC systems with one available gas analyser, whilst in 2017 both systems were sampled simultaneously with two available gas analyser."

17. RC: *16. p06L01 (Table 2): ppp for pressure seems unusually long/complicated. Also, in the row that is solely about ppp it looks a bit lonely (and hard to understand) without the long explanation "Atmospheric pressure". I acknowledge that you aimed at consistently giving the long name only upon first occurrence in the table, but here would be space and reason enough for an exception. Or maybe the row could be switched with the BME280.*

17. AR: We named it P_A for atmospheric pressure.

18. RC: *17. p07L19: "unpublished data" and then no matching entry in the reference list is a bit vague. If there is not even an internal report to refer to (which could then be listed in the references), "pers. comm." would probably be more appropriate, and at any rate in this case the institutional affiliation of Schmidt et al. should be given e.g. in the acknowledgement, to ensure traceability.*

18. AR: We changed this in the main text and in Table A2:

"Marcus Schmidt (pers. comm., Georg August University of Goettingen, Buesgen Institute, Soil Science of Tropical and Subtropical Ecosystems)"

Table A2. Site specific soil characteristics, with the soil texture being representative for the top soil column of 0.3 m. The bulk density is representative for the top soil column of 0.05 m. Data provided by Göbel et al. (2018) and Marcus Schmidt (pers. comm., Georg August University of Goettingen, Buesgen Institute, Soil Science of Tropical and Subtropical Ecosystems).

Site	Clay content (%)	Sand content (%)	Bulk density (kg m^{-3})
Dornburg AF	20.5	3.75	1.22
Dornburg MC	38	10.75	1.19
Forst AF	7	60.75	1.3
Forst MC	9.5	66.75	1.28
Mariensee AF	11.75	48	–
Mariensee MC	31.67	54.33	1.28
Reiffenhausen AF	23.75	31.5	1.28
Reiffenhausen MC	22.75	49.75	1.28
Wendhausen AF	35	18.25	1.085
Wendhausen MC	44.5	27	0.89

19. RC: *18. p07L28 (Sect. 2.2.3): Even though referring to a publication about the method where all this can probably be read in detail, not mentioning that there was a (probably large) spectral loss correction falls back behind the information given in the introduction (p03L17), and will make readers looking for this information in the methods section (the most logical place) wonder if and how this method could work at all.*

19. AR: We included more back-ground information on how the set-up worked in this section and for reproducibility also equations on how we transformed RH, TA and PA readings into a water vapour mole fraction into the Appendix.

Please find here the extended section 2.2.3:

2.2.3 Low-cost eddy covariance (EC-LC)

The EC-LC set-ups comprised of the same ultrasonic anemometer uSONIC3-omni as used for the EC and ECEB set-ups plus a compact low-cost relative humidity, air temperature and pressure sensor (BME280, BOSCH, Germany, Table 2). Water vapour mole fraction was calculated using measurements of relative humidity, air temperature and air pressure from the low-cost thermohygrometer. A derivation of the water vapour mole fraction from the low-cost thermohygrometer is given in Section A2. The turbulent water vapour fluxes were calculated as the covariance between the vertical wind velocity and the water vapour mole fraction from EC-LC, as per the principle of the eddy covariance method (Baldocchi, 2014). The cheaper but slower thermohygrometer had inferior spectral response characteristics compared to a gas analyser of fast response. The mean spectral correction factor of the thermohygrometer was 42% larger than for the LI-7200 fast response gas analyser for reference, with a 78% larger mean time constant of the thermohygrometer compared to the LI-7200. The mean time constant of the thermohygrometer and the LI-7200 was 2.8±1 s and 0.6±0.3 s, respectively (Markwitz and Siebicke, 2019). Spectral losses in the high-frequency range of the thermohygrometer were corrected by the fully analytical correction method of Moncrieff et al. (1997), which was explicitly recommended for either open-path sensors or closed-path sensors of heated and very short sampling lines. A detailed description and application of the EC-LC set-up for evapotranspiration measurements over AF and MC is given in Markwitz and Siebicke (2019). Evapotranspiration from EC-LC was neither gap-filled for the methodological comparison nor for the analysis of the energy balance closure due to the risk for new errors and artefacts from the respective gap-filling method.

And please find here the Appendix from the revised version of the manuscript:

A2 Water vapour mole fraction $C_{H_2O_v}$ from the thermohygrometer

The derivation of the water vapour mole fraction $C_{H_2O_v}$ from relative humidity, air temperature and air pressure from the low-cost thermohygrometer was also presented in Markwitz and Siebicke (2019) and for completeness given in this section.

The water vapour mole fraction, $\mathrm{C_{H_2O_v}}$, was derived from the definition of the specific humidity, q, as the quantity of water vapour per quantity of moist air. The latter two quantities were expressed as the density of water vapour, $\rho_{\mathrm{H_2O_v}}$, and moist air, ρ_{m}, respectively. The density of moist air is defined as the sum of the density of dry air, ρ_{d}, and the density of water vapour.

$$q = \frac{\rho_{H_2O_v}}{\rho_m} = \frac{\rho_{H_2O_v}}{\rho_d + \rho_{H_2O_v}} \tag{A4}$$

We then replaced the density of water vapour and the density of dry air in Eq. (A4) as per Eqs. (A5) and (A6), respectively,

$$\rho_{H_2O_v} = \frac{C_{H_2O_v} \cdot M_{H_2O_v}}{V_m} \tag{A5}$$

$$\rho_d = \frac{p - e_a}{R_d \cdot T} \tag{A6}$$

with the molar mass of water vapour, $\mathrm{M_{H_2O_v}} = 18.02\,\mathrm{g\,mol^{-1}}$, the molar volume of air

$$V_m = \frac{\Re \cdot T}{p}\,(\mathrm{m^3\,mol^{-1}}), \tag{A7}$$

the universal gas constant, $\Re = 8.314\,\mathrm{J\,mol^{-1}K^{-1}}$, and the specific gas constant of dry air, $R_d = 287.058\,\mathrm{J\,kg^{-1}\,K^{-1}}$.

Solving Eq. (A4) for $\mathrm{C_{H_2O_v}}$ leads to the water vapour mole fraction

$$C_{H_2O_v} = \frac{q\,\Re\,(p - e_a)}{p\,M_{H_2O_v}\,R_d(1-q)}. \tag{A8}$$

The specific humidity in Eq. (A8) was calculated as a function of relative humidity, temperature and air pressure measurements from the thermohygrometer:

$$q = 0.622 \cdot \frac{e_a}{p} \tag{A9}$$

The actual vapour pressure, $\mathrm{e_a}$ (kPa), in Eq. (A9) was calculated from an approximation of the saturation vapour pressure, $\mathrm{e_*(T)}$ (Stull, 1989) and from relative humidity, RH,

$$e = \frac{RH \cdot e_*(T)}{100} \tag{A10}$$

$$e_*(T) = 0.6112\,\exp((17.67T)/((T + 273.15) - 29.66)) \tag{A11}$$

(A12)

20. RC: *p08L27 (Sect. 2.3.2): This sentence at a first glance seems to contradict the sentence at the top of the same page. Maybe start like this: "Unlike for the methodological comparison and energy balance analysis, a gap-filling of EC-LC could not be avoided for [this and that, surely not for annual ET sums]. Therefore, for these analyses..."*

20. AR: We changed this in the revised version of the manuscript:

> Unlike for the methodological comparison and energy balance analysis, a gap-filling of ET_{EC-LC} could not be avoided for the calculation of annual sums of ET. Therefore, for these analyses we gap-filled the half-hourly ET_{EC-LC} with half-hourly ET_{ECEB} and corrected both ET_{EC-LC} and ET_{ECEB} for the surface energy balance closure as follows

21. RC: *p09L10-15 (Sect. 2.4): At the beginning consider replacing "As the" by "By". Citing software tools / packages can be useful when a) advertising that the own code can be made available to the reader or when b) Reproduction of results depends on using the same tool (mention package, e.g. because the method is so complicated it might give different results in other langauges). The major axis however is a statistical term independent of and introduced before R, and if correctly implemented in the package should yield the same result as any self-written implementation. Therefore it seems more important to refer to a statistical textbook or paper - e.g. Webster 1997, Eur. J. Soil Sci. 48:557, doi:10.1111/j.1365-2389.1997.tb00222.x (which by the way also provides in its "calibration" section support for your decision in other places to treat variables to be filled as "dependent" (Y) variables in a regression).*

21. AR: We considered the publication and changed the text:

> **2.4 Energy balance closure estimation**
>
> The energy balance closure (EBC) was quantified in two ways:
>
> 1. As the linear regression between the available energy (R_N - G - S), and the sum of the turbulent flux components (LE + H). We applied the major axis linear regression (Webster, 1997), which assumes equally distributed errors in both time series. We interpret the slope between the available energy and the sum of the turbulent fluxes as the closure of the surface energy balance. A slope of one and an intercept of zero corresponds to perfect energy balance closure. In the present study both the slope and the intercept were considered as variable.

22. RC: *p13L01 (Fig. 3): Cannot see MC footprint in subpanel d, is this somehow related to the inavailability of a campaign at Reiffenhausen mentioned at p08L24? But footprint modelling only relies on data measured anyway by the EC-H setup needed for ECEB and EC-LC? Maybe it would be good to state in a prominent place (or each time a particular result seems to be missing, e.g. in Fig. 3d, Fig. 4 between g and h, Table 3 row Mariensee EC-LC, Fig. 5, Table 4, Fig. 9) what was the reason (in most cases it seems to be the missing campaign at Reifenhausen MC, but not so e.g. in table 3).*

22. AR: The footprint at Reiffenhausen MC is missing due to the unavailability of a campaign there. Yes, the footprint estimation depends only on mentioned variables, but since the campaign did not take place, we decided to not include the data for the particular site and time period. It would distract from the interpretation of ET during the campaign over the AF in Reiffenhausen. In the footprint climatology for the whole year (Fig. A3 in the appendix) we did include Reiffenhausen MC, as this information is used to explain potential differences in annual sums of ET. We clarified where and why data were missing in the following figures and tables of the revised version of the manuscript: Tables 3-5; Figures 3-6, 8, 9, A1, A2, A5

23. RC: *p17L26 (Sect. 3.4.2 / describing Fig. 6): Is "square" a commonly recognized or self-explaining description of this kind of diel curve?*

23. AR: we rewrote the sentence to:

“The diel cycle of the EBR for Dornburg (Fig. \ref{fig:EnergyBalanceRatio}) show a strong increase between 6 am and 8 am, followed by a positive slope between 8 am and 2 pm, and a strong increase thereafter until 6 pm. The EBR is minimum 0 at 6 am and maximum 1.8 at 6 pm.”

24. RC: *p20L29 (Sect. 3.4.3): It took (me) several readings to understand how and why you changed magnitudes, after talking about measured data all the time. Basically the idea of this whole section is simpler and more straightforward than it looks, and if needing to shorten the paper, this (writing it simpler or dropping it completely) would be my first suggestion. It can be reduced to the message "the importance of a relative uncertainty in a flux for the EBC scales with the magnitude of that flux". Even this effect probably vanishes when looking at absolute rather than relative errors / uncertainties, and even though it is not completely irrelevant for deciding how much to invest into improving which flux, it could probably also be demonstrated in a more general way with symbolic maths or a thought experiment.*

24. AR: We removed this section.

25. RC: *p25L04 (Sect. 3.5.2) "related" reads strange in this context, maybe "plots with an ET index".*

25. AR: We changed this accordingly:

“The figure indicates first that plots with an ET index larger than one were water limited, [...]”

26. RC: *p26L05 (Sect. 3.5.3): "reduce" or "reduced"? The former simply repeats (and takes for granted, but this semms save to me) what the cited references state, while the latter implies a claim that it can be seen well in your data, which should then however be confirmed by a clearer statement.*

26. AR: ‘reduce’ represents better what we wanted to say!

27. RC: *p26L01 (Sect. 3.5.3): The methodology section preferred aerodynamic conductance, here aerodynamic resistance (the inverse) is used. Consistently using only resistance or conductance could help to avoid confusion.*

27. AR: We changed it to ‘Aerodynamic resistance’ in the methodology section.

28. RC: *p31L06 (acknowledgements): Data from other sites than your own seem to have been used only in one place of the appendix, Fig. A6, if I didn’t overlook something. If it is needed at all (there seems to be little connection to the main text), the small amount of sites used there seems to suggest that acknowledgements to the individual site PIs is at least as, or more, important than to the (for this number of sites quite lengthy) list of networks.*

28. AR: This was no longer needed, as we removed the figure from the appendix.

List of major changes in the manuscript

1. We tidied up the manuscript and strengthened the discussions in the results section.

2. Instead of using any available equation for the calculation of the "potential ET" we decided to follow the initial idea of Budyko, who assumed that a sufficient amount of available energy is needed to evaporate precipitation. Therefore, we plotted the relationship between ET/P and R_N/P, with R_N the net radiation, instead of ET/P vs. ET_P/P. The different approaches for ET_P gave very different results with differences in ET_P of ~100 mm a^{-1} across the different approaches. We removed related information on the Priestley-Taylor equation from the manuscript.

3. We included a new section in the appendix named derivations. There, we included 1) the derivation of the soil storage flux and the conversion of LE to ET, 2) equations for the calculation of a water vapour mole fraction from relative humidity, air temperature and pressure from the low-cost thermohygrometer and 3) the derivation of the canopy resistance from the rearranged Penman-Monteith equation and the aerodynamic resistance.

4. We removed the descriptive text in the Section on meteorological conditions and phenological state and referred only to the figure with time series and a table with mean values of relevant meteorological parameter from the campaigns.

5. We removed Section 3.4.3 "EBC sensitivity analysis".

6. We changed the letters in the sub-figures to site names, for example Forst AF and Forst MC instead of (a) or (b).

7. We included a new figure (Fig. 8) and a new section 3.5.1 "Sums of evapotranspiration during the campaigns" with cumulative sums of ET from all three methods (EC, EC-LC, ECEB) for the campaign periods at all sites.

8. We included an extra figure (Fig. 7) with diurnal cycle of the energy balance components for Dornburg AF and MC to explain the unexpected diel cycle of the energy balance ratio at the site.

9. We clarified the meaning of the abbreviations AF and MC early in the Abstract and in the introduction, which correspond to short rotation alley cropping agroforestry (AF) and monoculture systems with crops and grasses, but without trees (MC).

Evapotranspiration over agroforestry sites in Germany

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Abstract. In past years the interest in growing crops and trees for bioenergy production increased. One agricultural practice is the mixed cultivation of fast growing trees and annual crops or perennial grass-lands on the same piece of land, referred to as one type of agroforestry (AF). The inclusion of tree strips into the agricultural landscape has been shown - on the one hand - to lead to reduced wind speeds and higher carbon sequestration above-ground and in the soil. On the other hand, concerns have been risen about increased water losses to the atmosphere via evapotranspiration (ET). Therefore it was our main objective to proof if we hypothesize that short rotation coppice agroforestry systems have higher ET water losses to the atmosphere via ET, compared to monoculture systems. agriculture without trees (MC). In order to test the hypothesis the main objective was to measure actual evapotranspiration of five AF systems in Germany and compare those to five monoculture systems in close vicinity to the AF systems.

We followed a replicated measurement design to investigate the impact of agroforestry (AF) on ET under consideration of different ambient conditions. We measured actual ET at five agroforestry AF sites in direct comparison to five monoculture (MC) sites in Northern Germany in 2016 and 2017. We used an eddy covariance energy balance set-up (ECEB) and a low-cost eddy covariance set-up (EC-LC) to measure actual evapotranspiration over each agroforestry and each monoculture ET over each AF and each MC system. We conducted direct eddy covariance (EC) measurement campaigns of approximately four weeks duration for method validation.

Results from the short-term measurement campaigns showed a high agreement between ET from EC-LC and EC$\mathrm{ET}_{\mathrm{EC-LC}}$ and $\mathrm{ET}_{\mathrm{EC}}$, indicated by slopes of a linear regression analysis between 0.86 and 1.3 (R^2 between 0.7 and 0.94) across sites. Root mean square errors of LE from EC-LC vs. EC $\mathrm{LE}_{\mathrm{EC-LC}}$ vs. $\mathrm{LE}_{\mathrm{EC}}$ were half as small as from ECEB vs. EC$\mathrm{LE}_{\mathrm{ECEB}}$ vs. $\mathrm{LE}_{\mathrm{EC}}$, indicating a superior performance of agreement of the EC-LC compared to ECEBset-up with the EC set-up compared to the ECEB set-up.

The overall effect of agroforestry on system-scale ET for the two years was small compared to the monoculture systems. Differences between annual With respect to the annual sums of ET over AF and MCfrom the two years and both measuring set-ups were not significant (p = 0.3557), we observed small differences between the two land-uses. We interpret this as an effect of compensating small-scale differences in ET when ET is measured on system-scale. A reduction of ET is expected to be strongest next to the tree strips due to reduced wind speed and limited incident radiation relative to an open field. Whereas next to and in between the tree strips ET is expected to increase due to higher incident radiationfor ET measurements on system-scale. Most likely, differences in ET rates next to and in between the tree strips are of the same order of magnitude but

of opposite sign and compensate each other on system scale. In contrast, we found a strong dependency of ET on the local climate, characterized by the evapotranspiration index throughout the year. Differences between annual sums of ET from the two methods were of the same order of magnitude as differences between the two land-uses. Compared to the effect of land-use and different methods on ET, we found larger mean evapotranspiration indices ($\sum$ET/precipitation). We observed significant ($p = 0.0007098$) higher mean evapotranspiration indices $\sum$P) across sites for a drier than normal year (2016) compared to a wet year (2017)independent of the land-use or method. This indicates that we were able to detect differences in ET due to different ambient conditions with the applied methods, rather than the potentially small effect of AF on ET.

We conclude that agroforestry has not resulted in an increased water loss to the atmosphere indicating that agroforestry in Germany can be a land-use alternative to conventional agriculture monoculture agriculture without trees.

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1 Introduction

In past years the interest in growing crops and trees for the production of bioenergy has increased, especially in the scope of climate change mitigation and carbon sequestration (Fischer et al., 2013; Zenone et al., 2015). One method of efficient biomass production is the cultivation of short rotation coppice (SRC), referred to as "any high-yielding woody species managed in a coppice system“ (Aylott et al., 2008). Typically, fast growing tree species, such as poplar or willow are used for SRC plantations. The trees are commonly harvested after a three to five year rotation period and used for energy and heat production (Aylott et al., 2008). SRC plantations are comparable to monoculture systems with a single tree species grown.

The cultivation of fast growing trees with annual crops or perennial grass-lands on the same piece of land is an example of agroforestry (AF) (Morhart et al., 2014; Smith et al., 2013) and has numerous environmental benefits relative to monoculture (MC) systems consisting only of crops or grasses without trees (Quinkenstein et al., 2009). De Stefano and Jacobson (2018) found that the inclusion of fast growing trees arranged into tree strips (short rotation alley-croppingalley cropping agroforestry) leads to a higher carbon sequestration above-ground and in the soil relative to monoculture systems. The additional biomass input from litter, dead wood and roots led to increased soil fertility (e.g. (Beuschel et al., 2018; Quinkenstein et al., 2009; Tsonkova et al., 201
Böhm et al. (2014) and Kanzler et al. (2018) reported reduced wind velocity leewards of the tree strips when oriented perpendicular to the prevailing wind direction. In addition, Cleugh (1998) and Quinkenstein et al. (2009) found that tree strips reduce incident solar radiation, leading to reduced air temperature (McNaughton, 1988). Effects of tree strips on microclimate are mostly attributed to a region next to the tree strips with the extent depending on tree strip properties, such as the space between the tree strips, their orientation relative to the prevailing wind direction, their density, height and width (Quinkenstein et al., 2009).

Evapotranspiration (ET) in AF is strongly affected by the tree strip properties and is the combined process of 1) evaporation from the soil and open water from leaf surfaces and 2) leaf transpiration (Katul et al., 2012). ET within AF is reduced on the downwind side of the tree strips caused by a wind velocity reduction (Cleugh, 1998; Davis and Norman, 1988; Kanzler et al., 2018; Quinkenstein et al., 2009; Tsonkova et al., 2012). Davis and Norman (1988) explained the reduction in ET by the protection of adjacent crops from dry air advection. The reduced dry air advection leads to a decreased vapour pressure deficit (~~VPD~~D), lowering ET (Kanzler et al., 2018). The potential reduction in ET in the vicinity of the tree strips leads to an increased soil water content downwind, with the potential for enhancing yield production (Kanzler et al., 2018; Swieter et al., 2019).

Currently, little is known about system-scale water use of heterogeneously shaped ~~alley-cropping~~ short rotation alley cropping agroforestry systems in Germany. The majority of previous studies focused on the water use of short rotation coppices, but not AF systems (Bloemen et al., 2016; Fischer et al., 2013; Schmidt-Walter et al., 2014; Fischer et al., 2018). Fischer et al. (2013) and Zenone et al. (2015) observed a lower annual sum of evapotranspiration over a poplar SRC in the Czech Republic and in Belgium compared to the annual sum of evapotranspiration over a reference grassland. This is contradictory to the assumption that SRC plantations are strong water consumers. For ~~agroforestry~~ AF systems we formulated the same hypothesis~~such as~~, i.e. system-scale evapotranspiration over ~~agroforestry~~ AF systems is higher compared to monoculture agriculture without trees.

However, the effect of ~~agroforestry~~ AF on system-scale evapotranspiration is site specific and ~~depend~~ depends on the local climate, the soil type, the water availability ~~as well as the agroforestry~~ and the AF design. Therefore, repeated measurements at different sites are essential for studies on the effects of ~~agroforestry~~ AF on evapotranspiration. Nevertheless, this requires methods of low maintenance with low power consumption, and moderate cost.

The most common approach for evapotranspiration measurements at ecosystem scale is the eddy covariance (EC) method (Baldocchi, 2003, 2014). EC provides a tool for real time flux measurements on a time scale of 30 minutes. The complexity and cost of traditional EC systems, however, usually limits the required replication of measurement units (Hill et al., 2017). An alternative method with lower costs is the eddy covariance energy balance method (ECEB) (Amiro, 2009). The latent heat flux (LE) is calculated as the residual of the energy balance components, i.e., the net radiation, the ground heat flux, the sensible heat flux and various storage terms. The ~~accuracy of the~~ ECEB method is limited by the ~~ability to close the surface energy balance (Foken, 2008a; Foken et al., 2010; Gao et al., 2017), because any non-closure would affect the flux estimates~~accuracy of the energy balance components, typically leading to an overestimation of latent heat fluxes. Therefore, we need to assess to what extent the energy balance is closed at the given sites. Another alternative method for measurements of evapotranspiration is the use of slower but cheaper humidity sensors resulting in a low-cost eddy covariance set-up (EC-LC) (Markwitz and Siebicke, 2019). The measurement principle follows the concept of the eddy covariance method, however, the fast response gas analyser is replaced by a slow response thermohygrometer. The slow response time of the humidity sensor limits the sampling of turbulent eddies across the whole energy spectrum, which we address by appropriate high-frequency corrections during preprocessing. For latent heat fluxes obtained by EC-LC the non-closure of the energy balance causes a flux underestimation as observed for traditional EC set-ups. Any potential non-closure we then address by direct measurements of the latent heat flux to estimate the energy balance non-closure and partition the residual energy to the sensible and latent heat flux.

The main hypothesis of the current work was that short rotation alley cropping AF systems have higher water losses to the atmosphere via ET, compared to monoculture agriculture without trees. In order to test the hypothesis the main objectives of the study are (1) to evaluate the eddy covariance energy balance (ECEB) and low-cost eddy covariance (EC-LC) method against

Table 1. Site locations and AF geometry.

Site	Coordinates	No. of tree strips	Distance between tree strips (m)	Orientation of tree strips	Tree height (m)	Agroforestry type	Agroforestry system size (ha)	Relative tree cover (%)
Reiffenhausen	51°24'N 9°59'E	3	9	NW-SE	4.73±0.32 (n=69) Malec (2017)	Willow-grassland	1.9	72
Mariensee	52°34'N 9°28'E	3	48	N-S	4.01±0.33 (n=96) Swieter and Langhof (2017)	Willow-grassland	7	6
Wendhausen	52°20'N 10°38'E	6	24, 48, 96	N-S	6.21±0.4 (n=114) Swieter and Langhof (2017)	Poplar-cropland	18	11.52
Forst	51°47'N 14°38'E	7	24, 48, 96	N-S	6.5±1.8 (n=161) Seserman (2017)	Poplar-cropland	39.1	12
Dornburg	51°00'N 11°38'E	7	48, 96, 125	NW-SE	6.4±0.64 (n=160) Rudolf (2017)	Poplar-cropland	51	8

direct eddy covariance (EC) measurements, and (2) to measure actual evapotranspiration of five AF systems in Germany and compare those to five monoculture systems in close vicinity to the AF systems using the two different approaches.

2 Materials and methods

2.1 Site description

This study was carried out as part of the project 'Sustainable Intensification of Agriculture through Agroforestry' (SIGNAL, http://signal.uni-goettingen.de/, last access: 19 January 2020), investigating the sustainability of AF systems in Germany. We performed measurements at five sites across Northern Germany (Fig. 1 left). Each site consisted of one AF ~~plot~~ system and one monoculture (MC) ~~plot (Figs. 1 b, d, f, h and j~~ system (Fig. 1 for an aerial photograph of the Dornburg, Forst, Mariensee, Reiffenhausen and Wendhausen site with ~~the AF and the~~ AF and MC selected). The AF ~~plots~~ systems are of a short rotation alley cropping type, with fast growing trees interleaved by either crops ~~or perennial grasslands (Figs. 1 a, c and i for~~ (Fig. 1 for images of the cropland AF systems ~~and Figs. 1 e and g for~~ in Dornburg, Forst and Wendhausen) or perennial grasslands (Fig. 1 for images of the grassland AF systems in Mariensee and Reiffenhausen). The crops and grasses at the monoculture ~~plots~~ systems undergo the same tillage and fertilization as the crops and grasses cultivated between the tree strips. The MC ~~plot~~ system serves as a reference to the AF ~~plot~~system. Table 1 specifies the site locations and the AF geometry.

2.2 Measurements

Measurements of meteorological and micrometeorological variables were performed since March 2016. At each AF ~~plot~~ system we installed an eddy covariance mast with a height of 10 m and at each MC ~~plot~~ system an eddy covariance mast with a height of 3.5 m. Each mast was equipped with the same meteorological and micrometeorological instrumentation. The standard set-up consisted of instruments measuring wind speed, wind direction, sensible heat flux, net radiation, global radiation, air

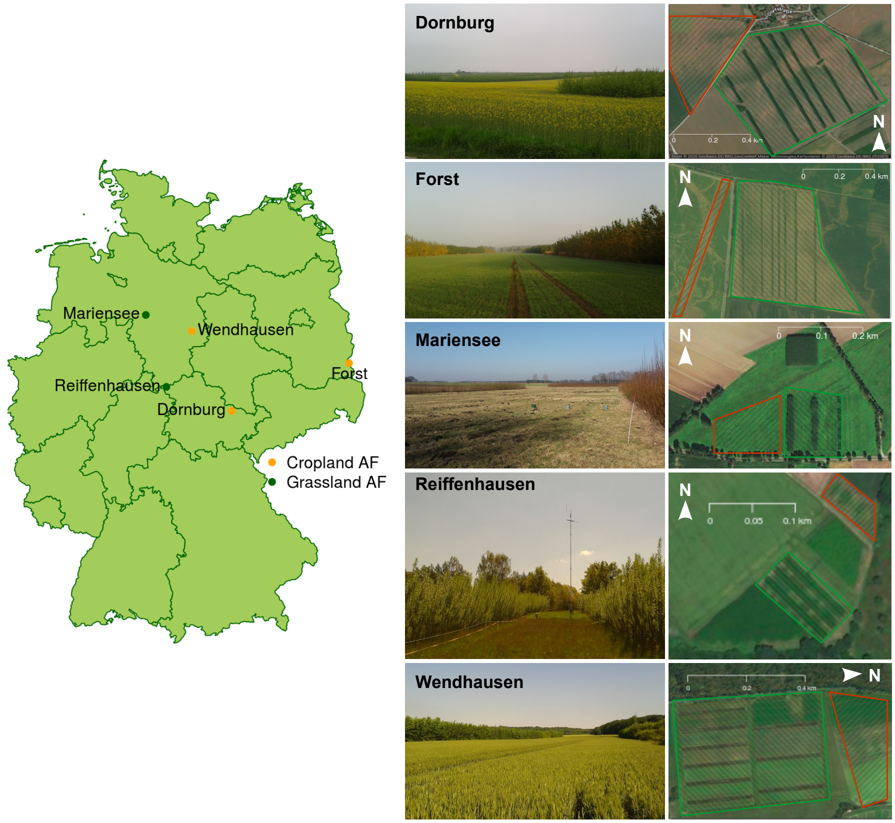


Figure 1. Left: map of SIGNAL sites, with the respective ~~agroforestry~~ AF type of either cropland or grassland AF; **Right:** image and aerial photograph of the AF systems~~of Dornburg, (a) and (b), Forst, (c) and (d), Mariensee, (e) and (f), Reiffenhausen, (g) and (h), and Wendhausen, (i) and (j)~~. Green hatched areas in the aerial photograph correspond to the area of the AF system and red hatched areas correspond to the area of the MC system. Site images are own photographs and aerial photographs originate from Google maps/ Google earth ©Google 2020.

temperature, relative humidity, precipitation and ground heat flux. An overview of the installed instruments and the respective variables used for the presented set-ups is given in Table 2.

Gaps in precipitation measurements at all sites were filled by precipitation data collected at nearby weather stations operated by the German weather service (DWD). We used the R-package rdwd (Boessenkool, 2019) for data download from the ftp server maintained by the DWD. We replaced gaps in precipitation measurements with DWD data if more than 25 % of precipitation data per day were missing. We used precipitation data from the weather stations Erfurt-Weimar airport, Cottbus, Hannover-Herrenhausen and Braunschweig to fill data gaps in precipitation at Dornburg, Forst, Mariensee and Wendhausen, respectively. In Reiffenhausen we used the precipitation records of a station placed at the same site and operated by the soil hydrology group at the University of Göttingen. As the precipitation transmitter was placed inside or next to the tree strips at the majority of the AF ~~plots~~systems, the measurements were affected by interception and were lower than at the MC ~~plot~~system. Therefore, we used the precipitation measurements from the MC ~~plot~~ system to compute ratios of annually summed actual

Table 2. Instrumentation for flux and meteorological measurements used at all five AF and MC plotssystems. Set-up corresponds to eddy covariance, EC, low-cost eddy covariance, EC-LC, and eddy covariance energy balance, ECEB.

Variable	Height (m)	Instrument	Company	Set-up
3D wind components, u, v, w ($m\,s^{-1}$) ultrasonic temperature, T_s (°C), wind speed ($m\,s^{-1}$), -direction (°)	3.5,10	uSONIC-3 Omni	METEK GmbH Elmshorn, Germany	EC, ECEB, EC-LC
Net radiation, R_N ($W\,m^{-2}$)	3, 9.5	NR-Lite2 Net Radiometer	Kipp&Zonen Delft, The Netherlands	ECEB
Global radiation, R_G ($W\,m^{-2}$)	3, 9.5	CMP3 Pyranometer	Kipp&Zonen Delft, The Netherlands	
Relative humidity, RH (%), air temperature, T (°C)	2	Hygro-Thermo Transmitter-compact (Model 1.1005.54.160)	Thies Clima Göttingen, Germany	EC, ECEB
RH, T, Atmospheric pressure, P_A (Pa)	0.5, 3/9.5	BME280	BOSCH, Germany	EC-LC
Precipitation, P (mm)	1	Precipitation Transmitter (Model 5.4032.35.007)	Thies Clima Göttingen, Germany	
P_A	0.5, 1.5	Baro Transmitter (Model 3.1157.10.000)	Thies Clima Göttingen, Germany	EC, ECEB, EC-LC
Ground heat flux, G ($W\,m^{-2}$)	-0.05	Hukseflux HFP01	Hukseflux Delft, The Netherlands	ECEB
Soil temperature, T_{Soil} (°C)	-0.02, -0.05, -0.10, -0.25, -0.5	DS18B20		ECEB, EC-LC
Water vapour mole fraction, $C_{H_2O_v}$ ($mmol\,mol^{-1}$)	3.5, 10	LI-7200	LI-COR Inc. Lincoln, Nebraska (USA)	EC
Carbon dioxide mole fraction, C_{CO_2} ($\mu mol\,mol^{-1}$)	3.5, 10	LI-7200	LI-COR Inc. Lincoln, Nebraska (USA)	EC

and potential ET ET and net radiation to precipitation at both AF and MC plotssystems. We assume that the annual sum of precipitation at the AF and the MC systems do not differ, due to the relatively small size of the AF systems and no expected local effects of the AF systems on the precipitation formation.

In the following sections we briefly describe the concepts of the used set-ups, eddy covariance (EC), eddy covariance energy-balance (ECEB) and low-cost eddy covariance (EC-LC). Throughout the manuscript paper we use the respective abbreviations.

2.2.1 Eddy Covariance (EC)

Sensible heat and momentum fluxes have been measured continuously with ultrasonic anemometers since 2016. The water vapour and CO_2 mole fraction were measured during field campaigns during the vegetation periods of 2016 and 2017. During the time of operation 2017 (Table A1). During the field campaigns the standard set-up was extended by an enclosed-path infrared gas analyser (LI-7200 , LI-COR Inc., Lincoln, Nebraska, USA). In 2016, the campaigns were conducted separately at the AF and MC systems with one available gas analyser, whilst in 2017 both plots systems were sampled simultaneously . All measuring periods are summarized in Table A1with two available gas analyser. Data processing and the analysis procedure is described in more detail in Markwitz and Siebicke (2019).

2.2.2 Eddy Covariance Energy-Balance (ECEB)

The energy balance at the surface is

$$R_N - G = H + \lambda E LE + S + Res \quad (1)$$

with net radiation, $\mathrm{R_N}$ ($\mathrm{W\,m^{-2}}$), ground heat flux, G ($\mathrm{W\,m^{-2}}$), sensible heat flux, H ($\mathrm{W\,m^{-2}}$), latent heat flux, LE ($\mathrm{W\,m^{-2}}$), ~~soil energy storage term~~and soil storage flux, S ($\mathrm{W\,m^{-2}}$)~~, and energy balance residual, ()~~. By convention a turbulent flux towards the atmosphere is defined as positive and a turbulent flux towards the surface is defined as negative. A positive net radiation corresponds to a surplus of radiative energy at the surface and a positive ground heat flux describes a heat transport into the soil.

~~The energy balance residual, , per half-hour interval was calculated from Eq. (1) as follows:~~

$$Res \quad = R_N - \lambda E - G - H - S$$

~~with from EC and EC-LC and from EC.~~

~~The from ECEB, ,~~LE from ECEB ($\mathrm{LE_{ECEB}}$) was calculated as the residual of the net radiation, the ground- and sensible heat flux~~and the storage term~~, and the soil storage flux according to Eq. (1)

$$\lambda E LE_{ECEB} = R_N - G - H - S - Res \quad (2)$$

~~whilst~~ assuming a fully closed surface energy balance.

~~Half-hourly evapotranspiration rates in units of were calculated from as~~

$$ET \quad = \frac{\lambda E_{ECEB}}{\lambda} \cdot 1800\,s$$

~~with the latent heat of vaporization (Dake, 1972)~~

$$\lambda \quad = (2.501 - 0.00237T) \cdot 10^6,$$

~~with being dependent on air temperature, T ().~~

~~The soil heat storage term has a major contribution to the unclosed energy balance (Foken, 2008a) and the magnitude~~ The conversion of LE into ET and the derivation of the soil ~~heat storage is comparably larger than the other storage terms, i.e. the photosynthesis flux , the crop enthalpy change, the air enthalpy change, the canopy dew water enthalpy change and the atmospheric moisture change (Jacobs et al., 2008). We used the ground heat flux, , from the ground heat flux measurements, (), at the sites and calculated the soil heat storage between the soil heat flux plate and the soil layer above following Liebethal and Foken (2007)~~

$$G = G_{HFP} + \int_{z=-0.05\,m}^{0\,m} c_v \frac{\partial T}{\partial t} dz$$

storage flux are given in Section A1.

The soil heat storage (second term on the right hand side of Eq. (A3)) consists of the vertical integral of the change of temperature over time at depth $z = 0.02$ m. c_v is the volumetric heat capacity of the soil, calculated from the soil components, i.e. organic, mineral and water and their respective heat capacities. Soil texture and bulk densities are summarized in Table A2 and were provided by Göbel et al. (2018) and Schmidt et al. (unpublished data) . Gaps in soil storage data were filled according to a multiple linear regression with soil storage as the independent variable, and net radiation and ground heat flux as the dependent variables. The multiple linear regression fitting parameter were derived from records when the soil storage, the net radiation and the ground heat flux were available at the same timeenergy balance residual, Res, per half-hour interval was calculated from Eq. (1) as follows:

$$Res = R_N - LE - G - H - S \tag{3}$$

with LE from either EC or EC-LC (LE_{EC} and LE_{EC-LC}, respectively) and H from EC.

2.2.3 Low-cost eddy covariance (EC-LC)

The EC-LC set-ups comprised of the same ultrasonic anemometer uSONIC3-omni as used for the EC and ECEB set-ups plus a compact low-cost relative humidity, air temperature and pressure sensor (BME280, BOSCH, Germany, Table 2). Water vapour mole fraction was calculated using measurements of relative humidity, air temperature and air pressure from the low-cost thermohygrometer. A derivation of the water vapour mole fraction from the low-cost thermohygrometer is given in Section A2. The turbulent water vapour fluxes were calculated as the covariance between the vertical wind velocity and the water vapour mole fraction from EC-LC, as per the principle of the eddy covariance method (Baldocchi, 2014). The cheaper but slower thermohygrometer had inferior spectral response characteristics compared to a gas analyser of fast response. The mean spectral correction factor of the thermohygrometer was 42% larger than for the LI-7200 fast response gas analyser for reference, with a 78% larger mean time constant of the thermohygrometer compared to the LI-7200. The mean time constant of the thermohygrometer and the LI-7200 was 2.8±1 s and 0.6±0.3 s, respectively (Markwitz and Siebicke, 2019). Spectral losses in the high-frequency range of the energy spectrum of the thermohygrometer were corrected by the fully analytical correction method of Moncrieff et al. (1997), which was explicitly recommended for either open-path sensors or closed-path sensors of heated and very short sampling lines. A detailed description and application of the EC-LC set-up for evapotranspiration measurements over AF and MC is given in Markwitz and Siebicke (2019). Evapotranspiration from EC-LC was neither gap-filled for the methodological comparison nor for the analysis of the energy balance closure due to the risk for new errors and artefacts from the respective gap-filling method.

2.3 Gap-filling and energy balance closure adjustment

2.3.1 ECEB

For the comparison of ET_{EC}, ET_{ECEB} and ET_{EC-LC} and the estimation of the energy balance closure during the campaigns, we neither gap-filled the data, nor corrected the data for the energy balance non-closure. For the calculation of annual sums of ET from ECEB data ET_{ECEB} and ET_{EC-LC} data gaps were filled, and corrected for the energy balance non-closure by distributing the residual equally to H and LE. The residual was estimated by machine learning for times when no data were available. In the following subsections we describe the gap-filling and energy balance closure adjustment procedures for the ECEB and EC-LC set-ups in more detail.

2.3.1 ECEB

For the calculation of annual sums of ET_{ECEB}, gaps were filled with the online eddy covariance gap-filling and flux-partitioning tool REddyProc developed at the Max Planck Institute for Biogeochemistry in Jena, Germany (https://www.bgc-jena.mpg.de/bgi/index.php/Services/REddyProcWeb, last access: 19 January 2020). The methods used therein are based on Falge et al. (2001) and Reichstein et al. (2005). We corrected ET from ECEB ET_{ECEB} for the average energy balance non-closure. We estimated the energy balance non-closure , which we estimated from direct LE measurements by EC during measurement campaigns . Considering of minimum four weeks duration. In the current study we found that considering the energy balance residual reduces ET from ECEB. ET_{ECEB}. We used machine learning to estimate the energy balance residuals (Eq. (3)) during times when no campaigns took place. We used the machine learning technique Extreme Gradient Boosting (Chen and Guestrin, 2016; Chen et al., 2019) and predicted the residual energy for both years, 2016 and 2017, at all sites with the R-package xgboost (Chen et al., 2019).

The calculated residual was treated as the dependent variable, whereas the net radiation, the ground heat flux and the sensible heat flux were treated as the independent variables. The model was tested with the data gathered during the campaigns and divided into a training period and a testing period. At a ratio of 2/3 of training to testing data, we achieved a Pearson correlation coefficient between the testing and predicted data of 0.66. The trained model was then applied to both years, with the net radiation, the ground heat flux and sensible heat flux as input parameters. As a last step the predicted residual was subtracted from half-hourly ET. We assumed that the residual distributes equally to the latent and sensible heat fluxLE and H, thus subtracted only half of the residual from ET. Commonly, the residual energy is partitioned according to the Bowen ratio (Twine et al., 2000), which requires direct and continuous measurements of H and LE by EC. We decided for an equal separation of the residual energy because direct LE measurements by EC were not continuously available at our sites. This assumption may cause an overestimation of LE during dry ambient conditions, when the Bowen ratio is high. In contrast, LE is expected to be underestimated during moist ambient conditions, when the Bowen ratio is small. As no campaign on the energy balance closure was conducted at the monocultural agriculture plot monoculture system of Reiffenhausen, we used the data gathered during the campaign at the AF plot system of Reiffenhausen to train the model and to predict the residual at the MC plotsystem.

2.3.2 EC-LC

Half-hourly ETrates from EC-LC were Unlike for the methodological comparison and energy balance analysis, a gap-filling of ET_{EC-LC} could not be avoided for the calculation of annual sums of ET. Therefore, for these analyses we gap-filled with half-hour ET rates from ECEB. The data were corrected the half-hourly ET_{EC-LC} with half-hourly ET_{ECEB} and corrected both ET_{EC-LC} and ET_{ECEB} for the surface energy balance closure as follows

1. The residual energy was estimated from all available data in 2016 and 2017, following Eq. (3).

2. We used the calculated residual as the dependent variable and the net radiation, the ground heat flux and the sensible heat flux as independent variables to train the same machine learning tool as used for ECEB.

3. The residual was predicted by the trained model; data gaps in the residuals, originating mainly from missing LE caused by data quality checks, were filled with the predicted values.

4. Subsequently, we distributed the residual to the half-hourly ET from EC-LC ($\mathrm{ET_{EC-LC}}$ ($\mathrm{LE^{cor}_{EC-LC}}$) and to ET from ECEB $\mathrm{ET_{ECEB}}$ used for gap-filling ($\mathrm{LE^{gf}_{ECEB}}$) as follows.

$$\alpha = 0.5 \tag{4}$$

$$\lambda E LE^{cor}_{EC-LC} = \lambda E LE_{EC-LC} + Res \cdot \alpha \tag{5}$$

$$\lambda E LE^{gf}_{ECEB} = \lambda E LE^{gf}_{ECEB} - Res \cdot \alpha \tag{6}$$

2.4 Energy balance closure estimation

The energy balance closure (EBC) was quantified in two ways:

1. As the linear regression between the available energy (R_N - G - S), and the sum of the turbulent flux components (λ E LE + H). We used the lmodel2 function from the lmodel2 R-package (Legendre and Oksanen, 2018) to compute the linear regression. The applied the major axis linear regression was applied(Webster, 1997), which assumes equally distributed errors in both time series. We interpret the slope between the available energy and the sum of the turbulent fluxes as the closure of the surface energy balance. A slope of one and an intercept of zero corresponds to perfect energy balance closure. In the present study both the slope and the intercept were considered as variable.

2. As the energy-balance-ratio (EBR) or also called "instantaneous energy balance closure" (Stoy et al., 2013), thus the closure per half an hour:

$$EBR = \frac{\lambda E + H}{R_N - G - S} \frac{LE + H}{R_N - G - S}, \tag{7}$$

with from either EC or EC-LCeither $\mathrm{LE_{EC}}$ or $\mathrm{LE_{EC-LC}}$.

2.5 Flux footprint analysis

The spatial coverage and the position of the source area of turbulent sensible- and latent heat fluxes, as well as and momentum at a specific point in time is defined by the flux footprint (Schmid, 2002; Kljun et al., 2015). In the present study a flux footprint climatology was calculated with the flux footprint prediction online data processing tool developed by Kljun et al. (2015) (http://footprint.kljun.net/, last access: 19 January 2020). The analyses were performed separately for the respective campaign periods (Table A1 for dates) and for both years at each site. We selected only daytime data, according to a global radiation $R_G > 20\ \mathrm{Wm^{-2}}$.

2.6 Canopy resistance

Effects of structural differences between AF and MC on ET were studied in terms of the relationship between half-hourly ET and the aerodynamic and canopy resistances ($\mathrm{s\,m^{-1}}$)and half-hourly ET. The canopy conductance was calculated using resistance was calculated from the rearranged Penman-Monteith equation (A12Eq. (A12)) for evapotranspiration, which depends on the canopy conductance, g_c (resistance, $\mathrm{r_c} = 1/\mathrm{g_c}$ ($\mathrm{s\,m^{-1}}$), and the aerodynamic conductance resistance for heat, g_{ah} ($\mathrm{r_{ah}} = 1/\mathrm{g_{ah}}$ ($\mathrm{s\,m^{-1}}$). The canopy conductance resistance follows the big leaf assumption, assuming that the whole canopy response to environmental changes is equal to equals the response of a single leaf. The Penman-Monteith equation for evapotranspiration of a canopy (Monteith, 1965) is

$$\lambda E \quad = \frac{s(R_N - G) + c_p VPD\, g_{ah}}{s + \gamma(1 + g_{ah}/g_c)}$$

with the vapour pressure deficit, , the heat capacity at constant pressure, c_p = 1005 , the saturation vapour pressure (hPa),

$$e_*(T_a) = 0.6112\exp((17.67T_a)/((T_a + 273.15) - 29.66)),$$

and the psychrometer constant, $\gamma = (c_p ppp)/(\lambda 0.622)$. The slope of the saturation vapour pressure curve, s, is

$$s = \frac{\varepsilon \lambda q_{sat}}{R_v T_a}$$

with $\varepsilon = 0.622$ and the specific humidity at saturation, $q_{sat} = \varepsilon e_*(T_a)/ppp$) as a function of temperature.

Rearranging Eq. (A12) yields the canopy resistance, r_c (),

$$r_c = \frac{1}{g_c} = \frac{s/\gamma + 1}{g_{ah}} \left[\frac{s/\gamma(R_N - G)}{(s/\gamma + 1)\lambda E} - 1 \right] + \frac{c_p VPD}{\gamma \lambda E}$$

The aerodynamic conductance for heat is

$$g_{ah} = \frac{\kappa^2 u}{\left(\ln\left(\frac{z-d}{z_{0m}}\right) - \psi_m(\zeta) \right) \left(\ln\left(\frac{z-d}{z_{0h}}\right) - \psi_h(\zeta) \right)}$$

with the von Karman constant, κ = 0.4, the horizontal wind velocity, (), the measurement height, (m), the displacement height, (m), estimated as 70 of the canopy height, This assumption is valid for the monoculture system with a single crop type of similar height. For the AF systems this assumption might be violated due to the heterogeneity of the AF systems with different plant species (trees and crops) of different heights. In the lee of the tree strips the reduced wind speed and incident radiation might lead to reduced ET due to a different leaf stomata regulation of sunlit and shaded leafs. In the windward site of the tree strips trees and crops are affected by increased wind velocities and varying incident radiation, thus opposite conditions compared to the lee of the tree strips. However, we assume that the meteorological data from the flux tower represent the mean state of the roughness length for momentum transport, , estimated as 10 of the canopy height and the roughness length for heat transport, , estimated as 10 of . is the universal function for momentum and is the universal function for heat. and depend on atmospheric stability with the stability parameter , including the Monin-Obukhov length, . and were calculated as

$$\psi_m(\zeta) = \begin{cases} 2\ln[(1+x)/2] + \ln[(1+x^2)/2] & \text{for } \zeta < 0 \\ -2atan(x) + \pi/2 & \\ & \\ -5\zeta & \text{for } \zeta \geq 0 \end{cases}$$

$$\psi_h(\zeta) = \begin{cases} 2\ln[(1+x^2)/2] & \text{for } \zeta < 0 \\ -5\zeta & \text{for } \zeta \geq 0 \end{cases}$$

with (Bonan, 2016; Businger et al., 1971; Stull, 1989)meteorological conditions within the AF system. Therefore, we are confident that the big-leaf assumption also holds for AF systems.

We studied the relationship between ET and canopy resistance as well as and aerodynamic resistance for idealized ambient conditions, with global radiation, $\mathrm{R_G} \geq 400\ \mathrm{W\,m^{-2}}$, horizontal wind speed, $\mathrm{u} \geq 1\,\mathrm{m\,s^{-1}}$ and vapour pressure deficit, (Schmidt-Walter et al., 2014).

In order to investigate the relationship between the dryness index (potential evapotranspiration divided by precipitation) and the evapotranspiration index (actual evapotranspiration divided by precipitation) we used the simplified Priestley Taylor equation after (Priestley and Taylor, 1972) to calculate a potential evapotranspiration. The Priestley Taylor equation depends only on available energy and air temperature

$$ET_{PT} = \alpha_{PT} \frac{s}{s+\gamma}(R_N - G)$$

with the Priestley-Taylor coefficient, $\mathrm{D} = 1 \pm 0.3\mathrm{kPa}$ (Schmidt-Walter et al., 2014). A derivation of the canopy resistance is given in Section A3.

3 Results and discussion

3.1 Meteorological conditions ~~and plant physiological stages~~ during the campaigns

~~During the measurement campaign at the MC plot of Dornburg (16 June to 14 July 2016, Fig. 2 a), we observed a mean air temperature of 18.6 and a mean vapour pressure deficit (VPD) of 7.35 . High mean air temperature and low rainfall of 2.1 over the campaign period led to rapid crop ripening.~~ For the meteorological conditions during the campaigns we refer to time series of relevant meteorological parameter in Figure 2 and mean values in Table 3.

~~At the cropland AF plot of Dornburg (14 July to 12 August 2016, Fig. 2 b) mean air temperature was 19 . The measuring period was characterized by frequent precipitation events with total rainfall of 57.1 mm. During this period poplar trees were at the seasonal maximum of their productivity and crops were mature.~~

~~During the measurement campaign at the grassland AF plot of Reiffenhausen (12 August to 14 September 2016, Fig. 2 c), we observed a mean air temperature of 19.31 , a mean VPD of 8.02 , and few rain events, accounting for 26.3 precipitation over this period. Both trees and grasses were at the maximum of their productivity.~~

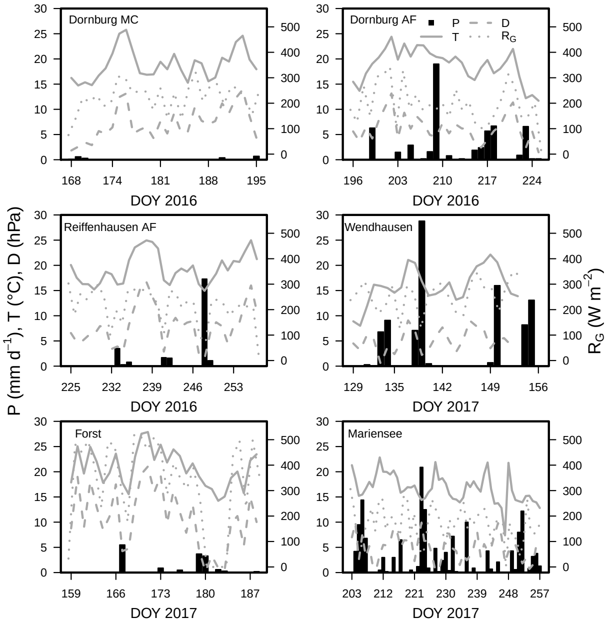
~~At the AF and MC plot of Wendhausen (03 May to 02 June 2017, Fig. 2 d) the mean VPD was 5.4 and 5.2 , respectively. High precipitation during the campaign (48.6 at the AF and 90.7 at the MC plot) meant water availability was not limited. The large difference in precipitation measurements was caused by the placement of the rain gauge inside the AF canopy. Mean daily air temperature was between 10 and 15 at the beginning of the campaign, whereas more moderate temperature was observed during the end of the campaign, between 15 and 20 . Mean air temperature was 16.6 at the AF and 15.5 at the MC plot over the entire campaign period.~~

~~In contrast, the measurement campaign in Forst (08 June to 08 July 2017, Fig. 2 e) was very warm with mean air temperature of 21.4 at the AF plot and 21.2 at the MC plot. Mean VPD was 12.02 and 11.88 and precipitation was 18.9 and 14.8 at the AF and the MC plots, respectively. The dry and warm conditions initiated the ripening process earlier, resulting in mature crops at the beginning of the campaign.~~

~~The last and longest measurement campaign at the grassland AF and MC plot of Mariensee (21 July to 19 September 2017, Fig. 2 f) followed the seasonal trend from high daily mean air temperature in July of 20 to lower daily mean air temperature in September at 15 . Mean VPD was 6.2 and 4.7 at the AF and MC plots, respectively. Precipitation during this period was 40.6 and 163.5 at the AF and MC plots, respectively.~~

3.2 Flux footprint climatology

The flux footprint analyses showed that the measured turbulent fluxes were representative for the larger AF ~~plots~~ systems and their respective MC ~~plots~~ systems during the time of the experiments (e.g. Dornburg, Forst and Wendhausen, ~~Figs. 3a, c and e~~Fig. 3). At the AF and MC ~~plots~~ systems of Dornburg 80 % of the flux magnitude originated from the respective system. The 90 % flux magnitude contribution line at the AF ~~plot~~ system overlapped with the 90 % flux magnitude contribution line at the MC ~~plot~~ system towards the west. The overlapping footprint was also found for the annual footprint analyses (Fig. A3~~a~~).



~~Time series of daily mean air temperature, T_A, vapour pressure deficit, VPD, daily summed precipitation (left y-axis) and daily mean global radiation, R_G, (right y-axis) for Dornburg MC, (a), Dornburg AF, (b), Reiffenhausen AF (c), Wendhausen (d), Forst, (e), and Mariensee, (f). The data for MC and AF of the respective sites of Wendhausen, Forst and Mariensee were averaged. The field campaigns at the AF and MC plots were conducted during the same time and we assumed similar weather conditions due to the small distance between the AF and MC plot.~~

Figure 2. Time series of daily mean air temperature, T (°C), vapour pressure deficit, D (hPa), daily summed precipitation ($\mathrm{mm\,d^{-1}}$) (left y-axis) and daily mean global radiation, R_G ($\mathrm{W\,m^{-2}}$), (right y-axis) for all sites. The data for AF and MC of the respective sites of Forst, Mariensee and Wendhausen were averaged. The field campaigns at the AF and MC systems were conducted during the same time and we assumed similar weather conditions due to the small distance between the AF and MC system.

At the AF and the MC ~~plot~~ system of Wendhausen we observed ~~an~~ a 80 % flux magnitude contribution from both land-uses to the total turbulent flux (Fig. 3~~e~~). A 10 % flux magnitude contribution originated from the forest around 200 m east of the flux tower. Easterly winds are most likely during stable atmospheric stratification in winter or summer. During the time of the experiment the wind mainly originated from westerly directions (not shown).

70 % of the area of the AF and MC grassland ~~plots~~ systems of Mariensee contributed to the measured fluxes, respectively (Fig. 3~~b~~). The remaining 20 % of the area contributing to the measured flux originated from surrounding crops and the AF and MC grassland systems. There was an overlap of the two footprints at the AF and the MC grassland ~~plot~~system, which was expected, as both flux towers are separated by a distance of about 200 m.

The fluxes measured at the smallest AF ~~plot~~ system in Reiffenhausen were influenced by fluxes originating from the nearby forests and crop fields about 400 m distance to the flux tower in northerly direction and about 200 m distance in southerly direction (Fig. 3~~d~~). Only 60 % of the fluxes originated from the willow-grassland AF system and the short rotation willow

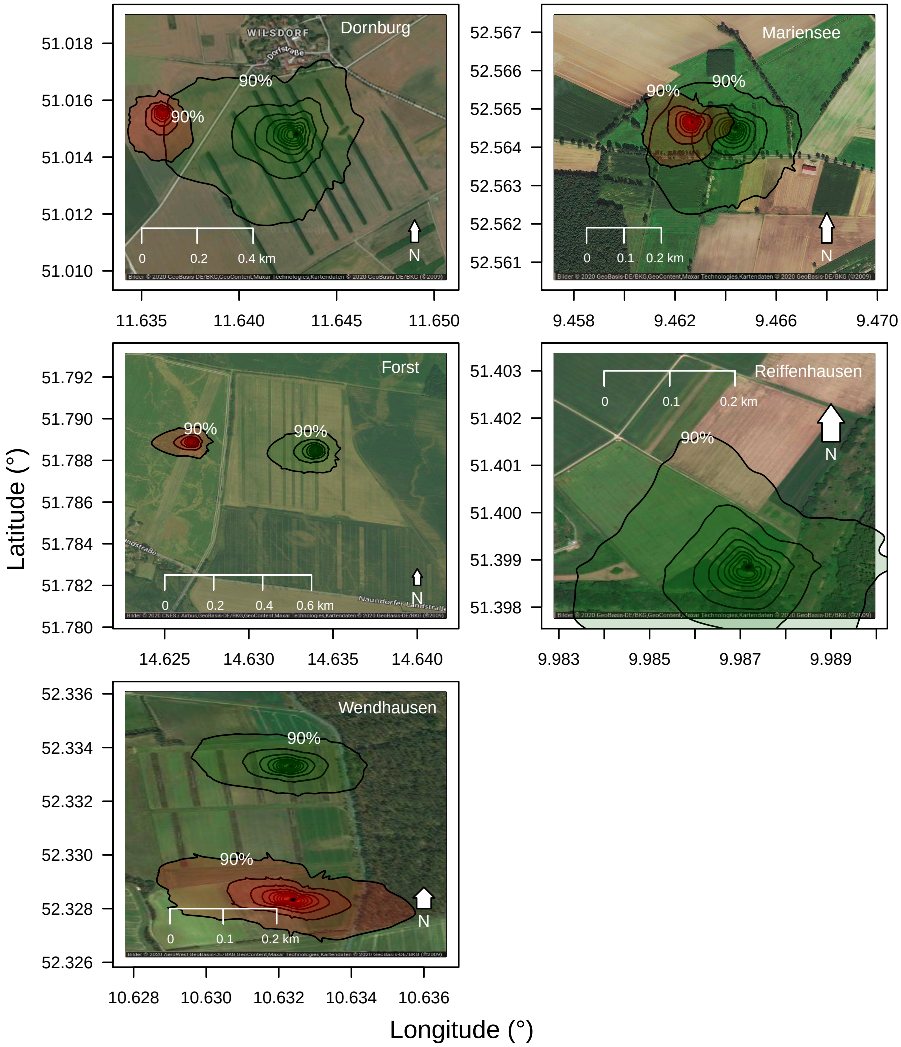


Figure 3. Flux footprint climatologies for ~~Dornburg, (a), Mariensee, (b), Forst, (c), Reiffenhausen, (d), and Wendhausen, (e),~~ all sites for the respective campaign period. Green shaded footprints correspond to the AF ~~plot~~ system and red shaded footprints correspond to the MC ~~plot~~system. For the analysis only daytime data were used ($R_G > 20\ \mathrm{W\,m^{-2}}$). Isolines correspond to a 10 to 90 % flux magnitude contribution in 10 % steps, with the 90 % isoline labelled in the ~~plot~~system. The flux footprint climatology for Reiffenhausen MC is missing due to the unavailability of a campaign. Aerial photographs originate from Google maps/ Google earth ©Google 2020.

Table 3. Mean air temperature, T (°C), vapor pressure deficit, D (hPa), global radiation, R_G ($W\,m^{-2}$), and the cumulative precipitation, P ($mm\,d^{-1}$), for the respective site and campaign period. Data for Reiffenhausen MC are missing due to the unavailability of a campaign.

Site	T (°C)	P (mm)	D (hPa)	R_G (Wm^{-2})
Dornburg AF	19.0	57.1	6.41	200.7
Dornburg MC	18.6	2.1	7.35	212.6
Forst AF	21.4	18.9	12.02	358.8
Forst MC	21.2	14.8	11.88	371.5
Mariensee AF	18.54	40.6	6.2	258.9
Mariensee MC	16.93	163.5	4.7	172.8
Reiffenhausen AF	19.31	26.3	8.02	219.1
Wendhausen AF	16.6	48.6	5.4	235.0
Wendhausen MC	15.5	90.7	5.2	239.9

plantation in the west. The terrain at the AF ~~plot~~ system of Reiffenhausen is sloped towards the north-west. The main wind direction at the site was north-northwest in the direction of the sloped terrain.

3.3 Diel evapotranspiration

The diel variation of ET for all three set-ups at all sites is depicted in time series plots for an exemplary time period in Figure 4.

The EC-LC set-up showed the best performance relative to direct EC measurements with coefficients of determination between minimum 71 % and maximum 94 %. The EC-LC set-up captured the temporal variability of ET and the flux response to changing ambient conditions as good as direct EC measurements. The slopes from a linear regression analysis of ~~LE from EC-LC versus EC~~ LE_{EC-LC} versus LE_{EC}, showed an agreement between 86 % and 99 % across four ~~agroforestry plots~~ AF systems and between 108 % and 142 % across four monoculture agriculture ~~plots~~ systems (Table 4 and Fig. A2).

At the MC ~~plots~~ systems of Forst and Wendhausen (Fig. 4~~d and i~~) we observed comparably high ~~fluxes obtained by EC-LC~~ ET_{EC-LC} relative to direct EC measurements, while attaining high coefficients of determination. We suspect that the laser source of the LI-7200 gas analyser did not work as expected as indicated by spectral analysis (data not shown). Only low-frequency fluctuations were sampled, whereas the high-frequency fluctuations were attenuated. The ~~measured water vapour mole fraction from the gas analyser was similar to the derived water vapor mole fraction from the thermohygrometer of slow response at the respective sites in terms of magnitude and temporal variability (data not shown). The similarity of the water vapor mole fractions indicate similar~~ spectral response characteristics of the gas analyser and the thermohygrometer set-up were similar. Therefore, the correction of high-frequency losses is expected to be higher for the compromised gas analyser at the respective MC ~~plots~~systems, than for a fully functional gas analyser.

~~ET obtained by the alternative ECEB set-up~~ ET_{ECEB} also captured the diel cycle of ET and gave an indication on the ecosystem response to changing meteorological driver (Fig. 4). ~~ET was overestimated by ECEB relative to EC~~ ET_{ECEB} overestimated ET_{EC} across all sites. A minimum overestimation of 27 % was observed at the AF ~~plot~~ system of Forst and a maximum overestimation of 101 % was observed at the MC ~~plot~~ system of Forst at half-hourly time scale (Table 4 and Fig. A1). Differences between ~~ET from ECEB and EC~~ ET_{ECEB} and ET_{EC} were attributed to the assumption of a fully closed energy balance at the surface (Foken et al., 2006). ~~ET from ECEB~~ ET_{ECEB} was calculated as the residual of net radiation, sensible heat flux, ground heat flux and soil storage. In this analysis we did not account for the commonly observed non-closure of the energy balance and added the surface energy balance residual completely to LE.

3.4 Energy Balance Closure (EBC)

3.4.1 EBC from EC and EC-LC

~~The EBC (% confidence interval) for LE from EC was 82% % and 88% % for Dornburg, 87% % and 78% % for Forst, 65% % and 75% % for Mariensee and 83% % and 76% % for Wendhausen, for the AF and MC plots, respectively, and 80% % for the AF plot of Reiffenhausen~~ The mean EBC was 79.4±8.5 % and 79.25±6 % across the five AF systems and four MC systems for LE_{EC} (Fig. 5 and Table 5). The coefficient of determination, R^2, was minimum 0.77 and maximum 0.92 across sites (Table 5).

The EBC for ~~LE from EC~~ LE_{EC} at the AF and the MC ~~plots~~ systems were comparable to agricultural systems as reported by Stoy et al. (2013), who found a mean EBC of 84±20 % across 173 FLUXNET sites, a mean EBC of 91 % to 94 % for evergreen broadleaf forests and savannas and a mean EBC of 70 % to 78 % for crops, deciduous broadleaf forests, mixed forests and wetlands. Imukova et al. (2016) found an EBC of 71 % and 64 % for two consecutive growing seasons over a winter wheat stand in Germany. Studying a belt and alley system in Australia Ward et al. (2012) found an EBC between 67 % and 80 % over the time period of half a year. Fischer et al. (2018) reported on water requirements of three short rotation poplar stands and found a mean long-term energy balance closure of 82 ~~%~~ % at a site in Italy, an EBC of 91 % or 95 % at a site in the Czech Republic and an EBC of 69 % at a site in Belgium. ~~At our sites we found a mean EBC of 79.4% 8.4across the five AF plots and a mean EBC of 79.25% 6across the four MC plots for LE from EC.~~

The EBC for ~~LE from EC-LC~~ LE_{EC-LC} was slightly lower at the AF ~~plots~~ systems with a mean EBC of ~~78% % , for five sites,~~ 79±5.3 % compared to the MC ~~plots~~ systems with a mean EBC of ~~81.4%~~ 82±11.8 % for five sites. ~~At the AF plots we observed a lower mean EBC from EC-LC compared to the mean EBC from EC.~~

The differentiation into lower EBC at the AF and higher EBC at MC ~~plots~~ systems observed for the two different set-ups is in agreement with the linear regression results presented in Section 3.3. At the AF ~~plots LE from EC-LC~~ systems LE_{EC-LC} was lower than ~~LE from EC~~LE_{EC}. In the calculation of the energy balance closure only LE was changed and the other energy balance components were held constant. Therefore, increased LE led to a decreased residual energy and subsequently to a better fit of the energy balance closure.

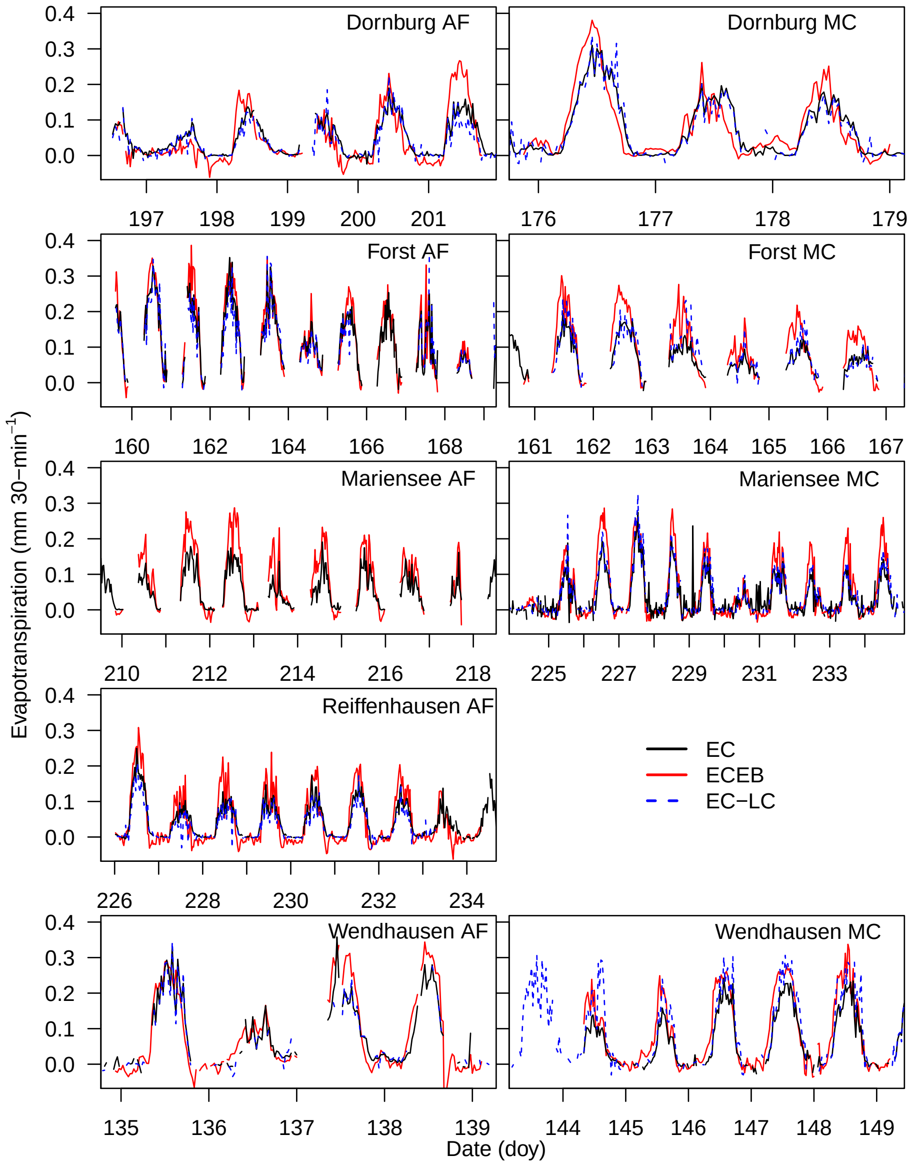


Figure 4. Time series of half-hourly evapotranspiration rates of an exemplary time period, for ECEB, EC-LC and EC as a reference ~~,~~ for ~~Dornburg AF, (a), Dornburg MC, (b), Forst AF, (c), Forst~~ all sites. Time series of half-hourly ET rates for Reiffenhausen MC ~~, (d), Mariensee AF, (e),~~ are missing due to the unavailability of a campaign and ET_{EC-LC} at Mariensee ~~MC, (f), Reiffenhausen~~ AF ~~, (g), Wendhausen AF, (h), and Wendhausen MC, (i)~~are missing due to technical problems of the sensor during the campaign. The presented time series were not corrected for the energy balance non-closure. Gaps in nocturnal data are due to the limited power availability from the solar power supply.

Table 4. Statistical analysis results for a linear regression of LE from EC-LC LE_{EC-LC} versus EC LE_{EC} and from ECEB LE_{ECEB} versus ECLE_{EC}. Shown are the root mean square error, RMSE, the standard deviation of the differences between both set-ups, SD, the bias, Bias, the number of points used for the analysis, n, the slope for a linear regression of LE from EC-LC LE_{EC-LC} versus EC LE_{EC} and from ECEB LE_{ECEB} versus ECLE_{EC}, as well as and the coefficient of determination of the linear regression, R^2. Data for LE_{EC-LC} at Mariensee AF are missing due to technical problems of the sensor during the campaign and data for Reiffenhausen MC are missing due to the unavailability of a campaign.

Sites	Method	RMSE (Wm^{-2})	SD (Wm^{-2})	Bias (Wm^{-2})	n	Slope	R^2
Dornburg AF	ECEB/EC	67.65	67.33	-6.23	1202	1.93	0.45
	EC-LC/EC	35	31.93	-11.14	1037	0.94	0.71
Dornburg MC	ECEB/EC	71.53	71.51	2.31	1152	1.33	0.52
	EC-LC/EC	34.31	34.3	1.1	1030	1.08	0.86
Forst AF	ECEB/EC	58.91	57	7.64	549	1.27	0.79
	EC-LC/EC	38.5	36.74	-2.13	197	0.95	0.9
Forst MC	ECEB/EC	74.5	61.70	18.42	612	2.01	0.7
	EC-LC/EC	37.9	34.5	5.3	461	1.42	0.8
Mariensee AF	ECEB/EC	79.79	65.54	23.82	1503	2.0	0.78
	EC-LC/EC	–	–	–	–	–	–
Mariensee MC	ECEB/EC	61.1	59.81	8.81	1852	1.42	0.75
	EC-LC/EC	44.6	43.9	4.62	1520	1.16	0.8
Reiffenhausen AF	ECEB/EC	55.4	55.23	4.1	1395	1.65	0.74
	EC-LC/EC	27.84	23.61	-2.72	279	0.86	0.9
Wendhausen AF	ECEB/EC	68.30	67.88	5.34	954	1.3	0.8
	EC-LC/EC	33.5	32.7	-3.1	586	0.99	0.94
Wendhausen MC	ECEB/EC	73.42	61.14	24.4	792	1.41	0.85
	EC-LC/EC	57.9	47	15.53	604	1.3	0.89

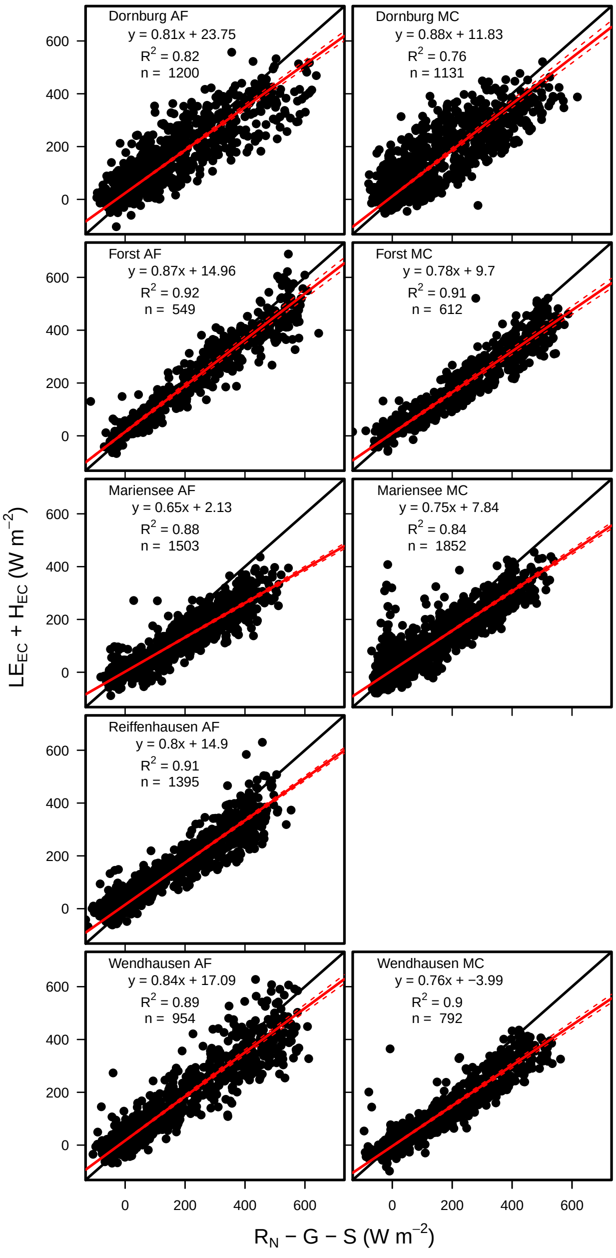


Figure 5. Scatterplot of the sum of the turbulent fluxes ($\mathrm{LE_{EC} + H_{EC}}$) versus the sum of the available energy ($\mathrm{R_N - G - S}$) for Dornburg AF, (a), Dornburg MC, (b), Forst AF, (c), Forst MC, (d), Mariensee AF, (e), Mariensee MC, (f), Reiffenhausen AF, (g), Wendhausen AF, (h), and Wendhausen MC, (i)all sites. The Each plot contains the linear regression equation, the coefficient of determination, R^2, and the number of data points used for the analysis, n. Data for Reiffenhausen MC are missing due to the unavailability of a campaign.

Table 5. Statistical analysis results of the linear regression between the sum of the turbulent fluxes and the available energy. Namely, the sites, the set-up used, the slope (±5 % confidence interval), intercept, the coefficient of determination of the linear regression, R^2, and the number of points used for the analysis, n. The energy balance closure determined by EC-LC at Mariensee AF is based on data collected from 23 March 2016 to 20 November 2016 and at Reiffenhausen MC the analyses are based on data collected from 07 April 2016 to 31 December 2016, ~~because no~~ due to the unavailability of data ~~were available~~ during the campaigns. The energy balance closure determined by EC for Reiffenhausen MC is missing due to the unavailability of a campaign.

Sites	Set-up	Slope	Intercept ($\mathrm{Wm^{-2}}$)	R^2	n
Dornburg AF	EC	~~0.82~~0.81± 0.02	~~23.52~~23.75±1.95	0.82	~~1202~~ 1200
	EC-LC	0.75± 0.03	~~17.01~~17.3±2.6	0.72	1088
Dornburg MC	EC	0.88± 0.025	~~10.67~~11.83±3.1	~~0.77~~ 0.76	1131
	EC-LC	0.90± 0.035	~~10.58~~12.03±~~4.0~~ 4.2	~~0.71~~ 0.70	1046
Forst AF	EC	0.87± 0.02	14.96±5.1	0.92	549
	EC-LC	0.81± 0.045	~~17.17~~17.2 ±11.1	0.85	205
Forst MC	EC	0.78± 0.02	~~9.66~~9.7±4.4	0.91	612
	EC-LC	0.85± 0.03	~~10.28~~10.3±7.9	0.85	486
Mariensee AF	EC	0.65± 0.01	2.13±1.63	0.88	1503
	EC-LC	~~0.81~~0.85± 0.009	~~1.7~~ -1±0.6	~~0.83~~ 0.85	~~6574~~ 6525
Mariensee MC	EC	0.75± 0.015	7.8±1.2	0.84	1852
	EC-LC	0.82± 0.015	7.7±1.4	0.88	1632
Reiffenhausen AF	EC	0.80± 0.01	14.94±1.2	0.91	1395
	EC-LC	0.72± 0.03	10.55±3.1	0.91	306
Reiffenhausen MC	EC	–	–	–	–
	EC-LC	~~0.60~~0.62± ~~0.006~~ 0.005	~~6.02~~5.7±~~0.37~~ 0.35	~~0.83~~ 0.84	~~9621~~9717
Wendhausen AF	EC	~~0.83~~0.84± 0.02	~~17.36~~17.1±2.8	0.89	954
	EC-LC	~~0.81~~0.82± 0.03	~~14.3~~13.8±4.4	0.84	641
Wendhausen MC	EC	0.76± 0.02	-3.9±2.6	~~0.91~~ 0.9	792
	EC-LC	~~0.90~~0.91± 0.025	~~3.11~~3.1±4.4	~~0.86~~ 0.85	710

3.4.2 Diel cycles of the energy balance ratio and the energy balance residual

The diel cycle of the energy balance ratio ~~(EBR) from EC at our~~ from LE_{EC} at the sites can be classified into two different patterns. The ~~first group of sites (Dornburg ,~~ diel cycle of the EBR for Dornburg (Fig. 6~~a, and Wendhausen, Fig. 6 e) show a square diel cycle of the EBR~~) show a strong increase between 6 am and 8 am, followed by a positive slope between 8 am and 2 pm, and a strong increase thereafter until 6 pm. The EBR is minimum 0 at 6 am and maximum 1.8 at 6 pm. The diel cycle of the EBR at the ~~second group of~~ remaining sites (Forst, ~~Fig. 6 b, Mariensee, Fig. 6 c, and Reiffenhausen~~ Mariensee, Reiffenhausen and Wendhausen, Fig. 6~~d~~) is lowest at 6 am and 6 pm with an EBR of 0.5, whereas between 8 am and 4 pm the EBR is fairly constant at a ~~level of 0.80 at Forst, 0.65 at Mariensee and 0.75 at Reiffenhausen. The mean EBRs are in the same~~ similar range as the EBC estimated for all sites and the whole campaign ~~. Sites with the first group (Dornburg and Wendhausen)~~(Table 5).

The Dornburg site might be affected by horizontal advection of ~~heat and moisture~~ moisture and heat. Oncley et al. (2007) reported that the advection of moisture had the highest contribution to the unclosed energy balance compared to the other components~~and the~~. The maximum peak of the horizontal moisture advection term was in the afternoon, as energy was accumulated during the day and released in the afternoon. We suspect that this is also the case for the Dornburg site. The sensible heat flux follows the diurnal cycle of available energy with the maximum peak at midday at the agroforestry and the monoculture system (Fig. 7). In contrast, the median of the latent heat flux had its maximum in the afternoon at around 2 pm and was positive even after the available energy changed its sign.

In addition to advective transport, the unclosed surface energy balance could be related to energy storage terms such as biomass, the air or photosynthesis (Jacobs et al., 2008), that have previously not been considered. The pattern seen at Dornburg ~~and Wendhausen~~ may be attributed to a release of energy during the afternoon, which correspond to a surplus of energy and a better closure of the energy balance. In the morning hours the storage terms have an opposite sign, which correspond to a lack of energy and a subsequent poorer energy balance closure. Considering the storage terms would lead to a reduction of the residual energy and a better closure of the energy balance.

Interestingly, the diel pattern of the EBR from ~~EC~~ LE_{EC} at both land-uses at all sites are equal. Additionally, the differences between the median diel cycle EBRs (between 6 am and 6 pm) at the AF and the MC ~~plot~~ system were small, with differences of ~~0.032 at Dornburg, 0.13 at Forst,~~ minimum -0.09 ~~at Mariensee and 0.13 at Wendhausen. At Reiffenhausen the EBR was only available for the AF plot. Positive differences indicate higher EBRs at the AF compared to the MC plots and vice versa. The median differences at the respective sitesaccount for 3.3 and 3.6 of the median diel EBR at the AF and the MC plots of Dornburg, for 14.0~~ and ~~16.7 at Forst, for 14.3 and 12.7 at Mariensee and 15.5 and 17.3 at Wendhausen, respectively~~maximum 0.13 across sites. As both flux towers located at the AF and the MC system at one site are separated by approximately 100 to 500 m and the diel patterns look similar, we suspect that the non-closed surface energy balance at one site is caused by local effects of longer wavelength than the commonly applied averaging period of 30 minutes and beyond the individual site level.

~~At the Dornburg and Wendhausen sites, the residual energy from EC, i.e. the differences between the available energy and turbulent fluxes, showed positive values during the morning and negative values during the night and transition times of sunrise and sunset (Fig. 6 a and e). We interpret the unequally distributed EBR as caused by unaccounted storage terms with a loss of~~

energy in the morning and a release of energy in the afternoon. At the remaining sites (Forst, Fig. 6 b, Mariensee, Fig. 6 c, and Reiffenhausen, Fig. 6 d) the diel cycle of the residual energy was highest during midday, whereas during the morning and the evening the residual energy was constant at around zero.

The diel cycles of the EBRs and the residuals were similar for both EC-LC and EC set-ups (Fig. A4). This is promising, as it indicates first, a performance of EC-LC comparable to EC, and, second, the capability of the EC-LC set-up to capture site-specific effects. Nevertheless, the observed differences between EBRs and residuals at the AF and MC at one site were mostly attributed to differences in LE. Higher LE from EC-LC than LE from EC LE_{EC-LC} than LE_{EC} led to higher EBRs.

3.5 Evapotranspiration over agroforestry

3.5.1 EBC sensitivity analysisSums of evapotranspiration during the campaigns

In this section, we investigate the response of the surface energy balance closure to changing energy balance components, e.g. the net radiation, latent-, sensible- and ground heat flux. The results should help to conclude on recommendations for the best installation of an eddy covariance flux tower inside agroforestry systems. For an estimate of the energy balance closure sensitivity to variation in the energy balance components, we changed the magnitude of each energy balance component by % separately for each site. Subsequently, we calculated a median energy balance ratio for each energy balance component across all sites .

We observed a decrease of the median energy balance ratio by 1.7 , 6.6 and 12.4 if the magnitude of ground-, the sensible- and the latent heat fluxes were decreased by 20 . For an increase of the flux magnitudes by 20 we observed an increase of the median energy balance ratio of 3.0 , 8.3 Sums of evapotranspiration for all three methods, all sites and 13.0 (Fig. ?? a-c). For the net radiation we observed the opposite, a decrease of the net radiation by 20 led to an increase of the energy balance closure by 29.2 , whereas an increase by 20 led to a decrease of the energy balance closure by 17.73 the campaign periods indicate higher sums of ET_{ECEB} relative to ET_{EC}, except for Dornburg AF (Fig. ?? d).

A change in the median EBR for increased or decreased energy balance components was always attributed to a change of the residual energy. In our study the soil storage term led to an increase in energy balance closure of 1 to 6 across sites. Despite the small effect of ground heat flux on EBR, the effect of unrepresentative ground heat flux measurements and the neglection of the soil storage term is not trivial (Foken, 2008a).

In homogeneous surfaces with low vegetation, ground heat flux and soil storage measurements are more representative for the ecosystem of interest than inside heterogeneous AF systems. Wilson (2002) found a phase-shift in the diel cycle of the ground heat flux relative to net radiation and turbulent fluxes inside heterogeneous AF systems. Those phase-shifts occur due to changing incident radiation at the surface, depending on the time of the day and the location of 8). The difference between sums of ET_{ECEB} and ET_{EC} reflect the unaccounted correction of ET_{EC} and ET_{ECEB} for the energy balance non-closure. The large difference between sums of ET_{ECEB} and ET_{EC} at Mariensee AF correspond to the heat flux plate. One solution for preventing those phase-shifts is to increase the number of heat flux plates and vertical soil temperature profiles. We distributed the heat flux plates and vertical soil temperature profiles in a horizontal transect perpendicular to the crop fields. This made it

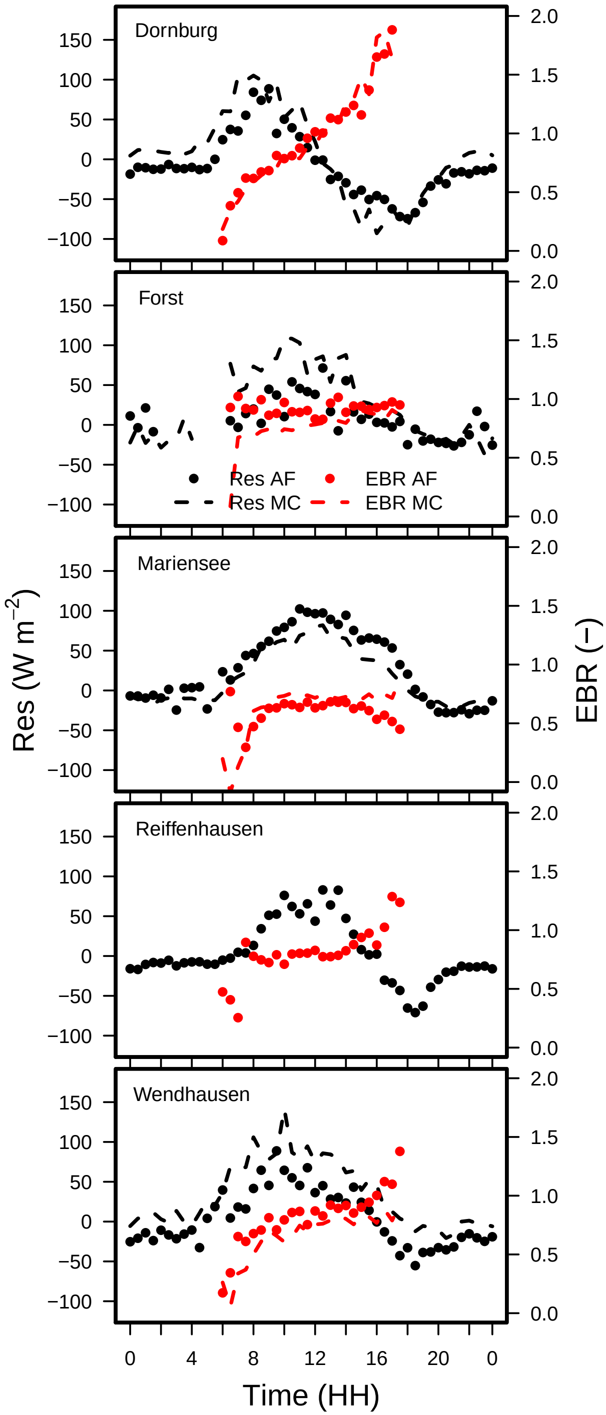


Figure 6. ~~Daily median~~ Median diel cycle of the energy balance ratio (EBR) and diurnal cycle of the residual energy ~~at Dornburg, (a), Forst, (b), Mariensee, (c), Reiffenhausen, (d), and Wendhausen, (e),~~ for the AF and the MC ~~plots, respectively~~systems at all sites. LE and H were obtained by EC. Data from Reiffenhausen MC are missing due to the unavailability of a campaign.

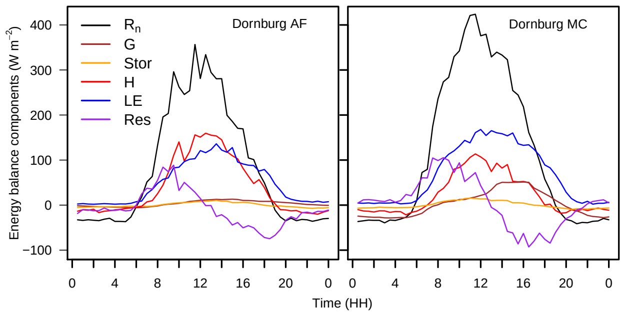


Figure 7. Median diurnal cycle of the energy balance components for Dornburg AF and MC for the campaign times (Table A1).

possible to measure the soil heat flux and soil storage at the two transition zones between crops and trees and within the tree strips.

Compared to the other energy balance components, net radiation had the strongest impact on a change of the EBR. Representative net radiation measurements are difficult to achieve over heterogeneous surfaces such as agroforestry systems. Depending on the placement of the whole measuring complex, either only above trees or above crops or at the transition zone between both trees and crops, the representativity and the magnitude of the measured net radiation varies. The only difference in net radiation for different plants originates from the reflected short wave radiation and emitted long wave radiation. To achieve a representative net radiation over AF we placed the tower on the edge between trees and crops, ensuring the net radiation was representative of that experienced by both tree and crop componentslow energy balance closure of 65 % at the site. Differences between sums of $\mathrm{ET_{EC-LC}}$ and $\mathrm{ET_{EC}}$ correspond to lower $\mathrm{ET_{EC-LC}}$ than $\mathrm{ET_{EC}}$ over the AF systems and higher $\mathrm{ET_{EC-LC}}$ than $\mathrm{ET_{EC}}$ over the MC systems. This is indicated by slopes smaller and higher one of a linear regression analysis between $\mathrm{ET_{EC-LC}}$ and $\mathrm{ET_{EC}}$ (Table 4).

3.6 Evapotranspiration over agroforestry

3.5.1 Weekly sums of evapotranspiration

The annual cycle of evapotranspiration across all sites and for the years, 2016 and 2017, depict the typical seasonal cycle of highest ET during summer and lowest ET during winter (Fig. 9). We found small differences between weekly sums of ET at the AF and the MC plots systems during the main growing period of the crops. After ripening of the crops, we found higher weekly sums of ET at the AF plots systems compared to the MC plots systems at the cropland sites of Dornburg(Fig. 9 a), Forst (Fig. 9 b) , Forst and Wendhausen (Fig. 9e). After). We assume that after the ripening of the crops evaporation contributed the most to the measured ET at the MC plotsystem, whereas at the AF plot system both evaporation from the crop fields between the tree strips and transpiration from the trees contributed to the measured flux. At the grassland sites of Mariensee and Reiffenhausen (Fig. 9c and d) differences in weekly sums of ET between both land-uses were small with a tendency of higher ET rates at the MC plot system compared to the AF plotsystem.

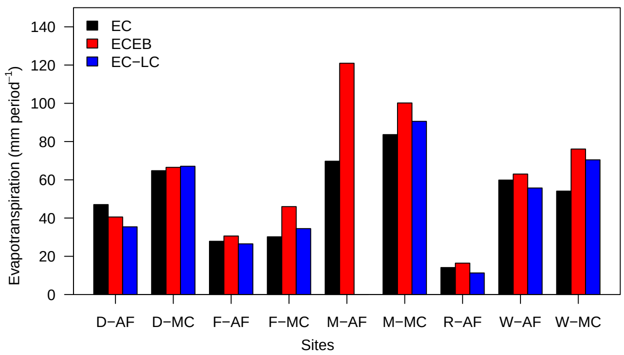


Figure 8. Daily median energy balance ratio for a variable ground heat flux, (a), a variable sensible heat flux, (b), a variable latent heat flux, (c), Sums of uncorrected and a variable net radiation, (d), for unbiased values (0), not gap-filled half-hourly evapotranspiration for 20increased all three methods and 20 % decreased values (+20all sites during the campaign periods. Sites are abbreviated by their first letter and -20contain either AF for agroforestry or MC for monoculture. Incomplete records with either $\mathrm{ET_{EC}}$, respectively)$\mathrm{ET_{ECEB}}$ or $\mathrm{ET_{EC-LC}}$ missing were omitted. Only daytime Data for $\mathrm{ET_{EC-LC}}$ at Mariensee AF are missing due to technical problems of the sensor during the campaign and all data were used with for Reiffenhausen MC are missing due to the unavailability of a global radiation $R_G > 20$ campaign.

3.5.2 Annual sums of evapotranspiration

We compared Differences between annual sums of ET for both land usesthe two land-uses, AF and MC, both set-ups, ECEB and EC-LC, and both years, 2016 and 2017 (Fig. 10).

In 2016, annual sums of ET from ECEB were higher over AF than over MC in Dornburg, Forst, Reiffenhausen and Wendhausen (6%, 21%, 10% and 10%) and lower in Mariensee by 16%. This was also found in 2017 for all sites (were in the range of maximum +31 % in Forst, -14% in Mariensee, +20% in Reiffenhausen and +11% in Wendhausen), except for Dornburg, where we observed a slightly lower ET over AF than over MC of 8and minimum -16 % (Fig. 10 a and b, and Table 6) .

Annual across sites and methods. We wanted to understand where differences between annual sums of ET from EC-LC in 2016 were higher over AF than over MC in Forst, Mariensee and Reiffenhausen (17%, 14% and 7%, respectively) , and slightly smaller over AF than over MC in Dornburg and Wendhausen (1% and 5%). In 2017, the annual sum of ET was higher over AF than over MC in Forst by 6% and vice versa in Wendhausen by 4% (Fig. 10 c and d, and Table 6) .

As shown, we only found little differences between annual sums of ET over AF and MC at our sites. Therefore, we wanted to understand how ET over the two land uses (AF and MC) respond to different local climatic conditions. come from. Therefore, we investigated differences between ET according to 1) the effect of the different land-uses, AF and MC, 2) the effect of different methods, EC-LC and ECEB, and 3) the effect of different years, 2016 and 2017, with different precipitation inputs. For this purpose we used the relationship between the evapotranspiration index ($\sum$ET/$\sum$P) and the aridity index ($\sum ET_p$radiative

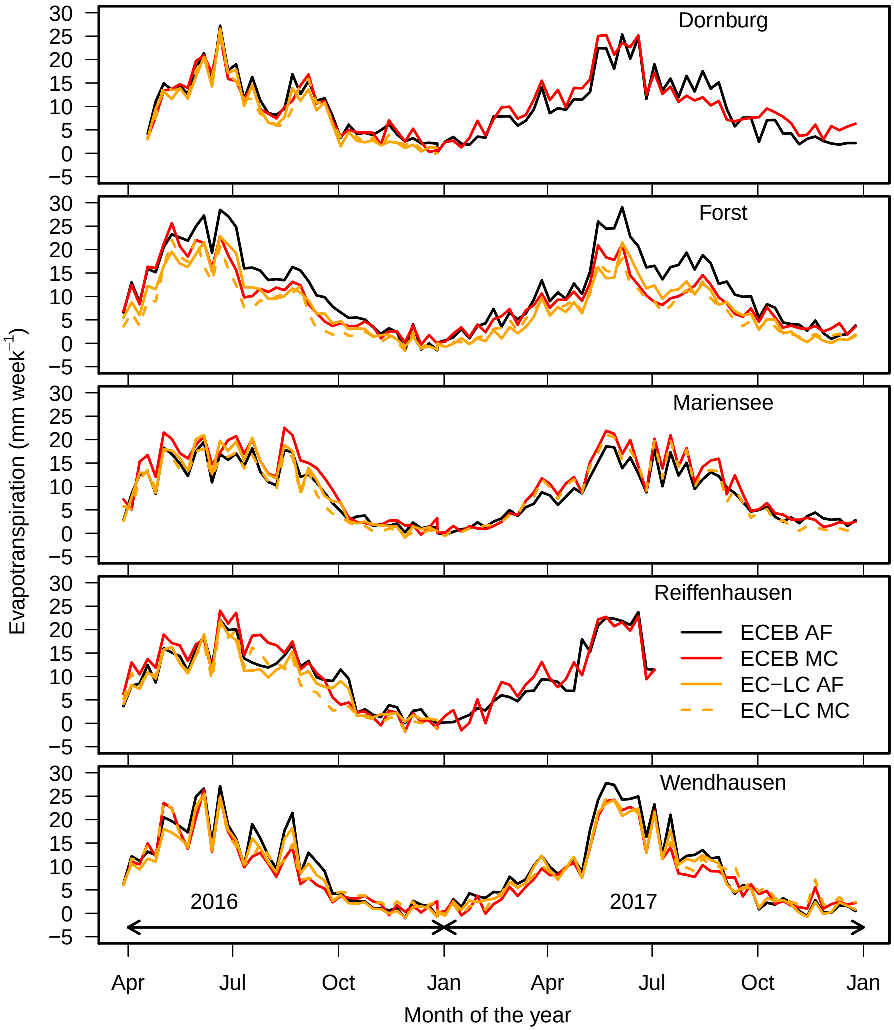


Figure 9. Weekly sum of half-hourly ~~ET rates from ECEB~~ $\mathrm{ET_{ECEB}}$ (black and red solid lines for AF and MC, respectively) and ~~EC-LC~~ $\mathrm{ET_{EC-LC}}$ (orange solid and dashed line for AF and MC, respectively) for ~~Dornburg, (a), Forst, (b), Mariensee, (c),~~ all sites. In 2017 data in Reiffenhausen ~~, (d),~~ AF and ~~Wendhausen, (e)~~MC were only available until the end of July due to station failure.

dryness index (R_n/~~$\sum$~~λP) proposed by Budyko (Budyko, 1974). ~~The local climatic conditions are considered in the calculation of the potential ET (Eq. ??), as per the available energy and air temperature.~~

~~Figure 11~~ Figure 11 (a) shows the ET index as a function of the ~~aridity~~ radiative dryness index for all sites, both set-ups and both years.

The figure indicates first that ~~those plots related to~~ plots with an ET index larger than one were water limited, corresponding to an ~~aridity index ET_p~~radiative dryness index R_n/λP>1. Secondly, the figure shows a separation of the sites with an energy limitation (~~ET_p~~R_n/λP<1) and water limitation (~~ET_p~~R_n/λP>1) for the years 2016 and 2017, respectively.

~~In~~ With regards to the first finding, in 2016 the grassland sites Mariensee ~~(~~AF and MC~~) and Reiffenhausen (AF)~~ , and Reiffenhausen AF had an ET index larger than one. At those sites, the annual sum of ET was generally high relative to the annual sum of precipitation (Fig. A5 c). This finding seems to be typical for grasslands. Williams et al. (2012) reported on average 9 % higher transformation of precipitation into evapotranspiration of grasslands compared to forests across 167 sites as part of the global FLUXNET flux measurement network. They concluded, first, that higher ET of grasslands may have been caused by the less conservative water use compared to trees and, second, that it could indicate that grasses have an extensive, well developed rooting system, similar to trees. Nevertheless, considering the water balance equation with precipitation equalling the sum of evapotranspiration and water runoff, an ET index larger than one indicates water losses via ET and no runoff. An ET index larger than one is only to be expected under ground water access, irrigation or the impact of a nearby stream. At the grassland site of Mariensee it is likely that the trees and grasses had ground water access, as the ground water table was at about 1.5-2 m depth. ~~The agroforestry~~

The AF system in Reiffenhausen is located on a gentle slope with no ground water access, which we expect should promote run-off, contrary to the high ET index observed. But, the ET measurements are affected by a poplar and willow SRC in the south-southeast and north-northwest directly within the flux footprint (Section 3.2 and Fig. 3). And with respect to the overall area of the ~~agroforestry~~ AF system, the area covered by trees amounts to 72 % and is much higher, compared to the other sites (Table 1). In both cases, ~~an aridity~~ a radiative dryness index larger than one is also possible, despite this indicating a water limitation at the particular sites. Additionally this also indicates a surplus of radiative energy, which promotes photosynthesis and higher transpiration, if water is not limited. In contrast, the Mariensee and Wendhausen sites had evapotranspiration and radiative dryness indices of approximately 0.5 and 0.6 in 2017. Those sites were affected by exceptionally high annual precipitation events, but annual sums of ET comparable to 2016 (Table 6).

The second finding gives evidence for a ~~strong~~ dependency of ET on the local climate. The years 2016 and 2017 correspond to a dry and a wet year, respectively. In Figure 11 (a) and (b), arrows indicate the difference between mean evapotranspiraion indices and mean radiative dryness indices grouped by year, method and land-use. The length of the arrows correspond to the overall ~~importance. As shown, the effect of different years with varying hydrological and weather conditions had the strongest impact on mean~~ difference. The ET index averaged over all annual sums of ET ~~, indicated by the movement of points~~ for the years 2016 and 2017 showed the largest difference, with a trend from a water limited (2016) regime to an energy limited (2017) regime. Higher available energy and lower precipitation than normal in 2016 led to a higher radiative dryness index, whereas lower available energy and higher precipitation led to a smaller radiative dryness index in 2017. Differences between mean ET

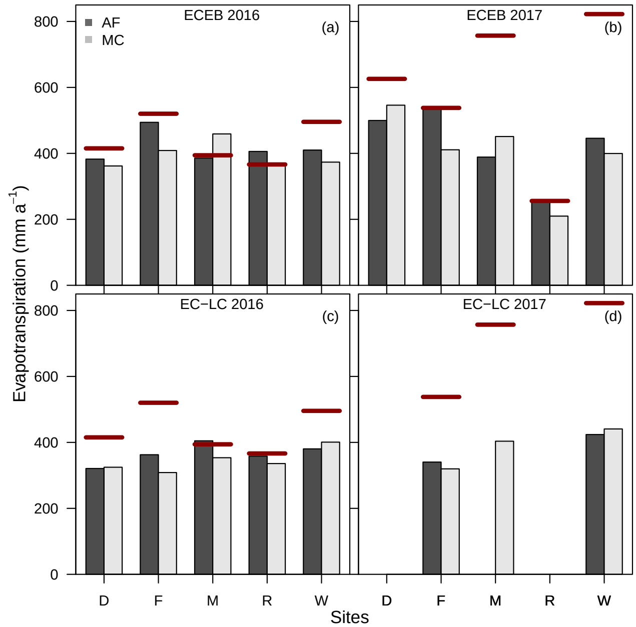


Figure 10. Annual sums of ~~evapotranspiration from ECEB~~ $\mathrm{ET_{ECEB}}$ in 2016, a, and 2017, b, and ~~from EC-LC~~ $\mathrm{ET_{EC-LC}}$ in 2016, c, and 2017, d, for Dornburg, ~~"D"~~, Forst, ~~"F"~~, Mariensee, ~~"M"~~, Reiffenhausen, ~~"R"~~, and Wendhausen, ~~"W"~~. The red solid lines correspond to the annual sum of precipitation from the ~~monocultural agriculture plot~~ monoculture system of the respective site. The annual sums of evapotranspiration at Reiffenhausen AF and Reiffenhausen MC in 2017 contain only data from 01 January 2017 to 09 July ~~2017.~~2017 due to station failure. Annual sums of $\mathrm{ET_{EC-LC}}$ for Dornburg AF and MC, Mariensee AF, Reiffenhausen AF and MC in 2017 are missing due to instrument malfunctions.

indices from the two methods had the second largest impact on annual sums, with a trend of ~~higher mean annual sums of ET obtained by ECEB compared to EC-LC~~a higher mean ET index of $\mathrm{ET_{ECEB}}$ compared to $\mathrm{ET_{EC-LC}}$. Land-use type had the least impact on ~~ET~~differences between the ET indices, with a small trend of higher ET/P over AF than over MC.

However, our results indicate that the effect of agroforestry on ET is small compared to differences between methods and differences between years with different precipitation regimes. We therefore reject the initial hypothesis that short rotation alley cropping agroforestry systems lead to higher water losses to the atmosphere via ET, compared to monoculture agriculture without trees.

3.5.3 Effect of agroforestry on ET as explained by aerodynamic and canopy resistance

We wanted to understand if the heterogeneity of the AF systems can explain differences between half-hourly ET rates from AF relative to MC systems. We quantified the effect of surface heterogeneity on ET as per the relationship between ~~the~~ half-hourly ET rates and aerodynamic and canopy resistances~~and half-hourly ET rates~~. Tree strips orientated perpendicular to the prevailing wind direction significantly ~~reduced~~ reduce the wind speed (Böhm et al., 2014) and the aerodynamic resistance (Lindroth,

Table 6. Annual sums of energy balance closure corrected actual evapotranspiration, ET ~~, potential evapotranspiration, ET_0~~($\mathrm{mm\,a^{-1}}$), and precipitation, ~~Rain,~~ P ($\mathrm{mm\,a^{-1}}$) for all sites, both set-ups (ECEB and EC-LC) and both years (2016 from April to December, and 2017 from January to December). ~~We included annual sums of uncorrected actual evapotranspiration obtained by ECEB in brackets.~~ The annual sums of ~~ET~~ $\mathrm{ET_{ECEB}}$ and precipitation at Reiffenhausen ~~for~~ AF and MC in 2017 contain data from 01 January 2017 to 01 July ~~2017.~~2017 due to destruction of the station. Annual sums of $\mathrm{ET_{EC-LC}}$ for Dornburg AF and MC, Mariensee AF, Reiffenhausen AF and MC in 2017 are missing due to instrument malfunctions.

Method	ECEB		EC-LC			
Sites	ET 2016	ET 2017	ET 2016	ET 2017	~~ET_0 2016 ET_0 2017 Rain~~ P 2016	~~Rain~~ P 2017
Dornburg AF	383 ~~(373)~~	500 ~~(494)~~	321	–	~~523 612~~ 414	626
Dornburg MC	362 ~~(307)~~	546 ~~(511)~~	325	–	~~456 594~~ 414	626
Forst AF	494 ~~(443)~~	540 ~~(453)~~	363	340	~~597 590~~ 520	538
Forst MC	409 ~~(435)~~	411 ~~(397)~~	309	320	~~589 550~~ 520	538
Mariensee AF	386 ~~(457)~~	389 ~~(433)~~	405	–	~~536 498~~ 394	757
Mariensee MC	459 ~~(466)~~	451 ~~(430)~~	354	404	~~536 467~~ 394	757
Reiffenhausen AF	406 ~~(390)~~	252 ~~(260)~~	358	–	~~512 330~~ 366	256
Reiffenhausen MC	368 ~~(414)~~	210 ~~(266)~~	336	–	~~534 302~~ 366	256
Wendhausen AF	410 ~~(417)~~	446 ~~(424)~~	380	424	~~553 536~~ 496	822
Wendhausen MC	373 ~~(490)~~	400 ~~(492)~~	401	440	~~609 547~~ 496	822

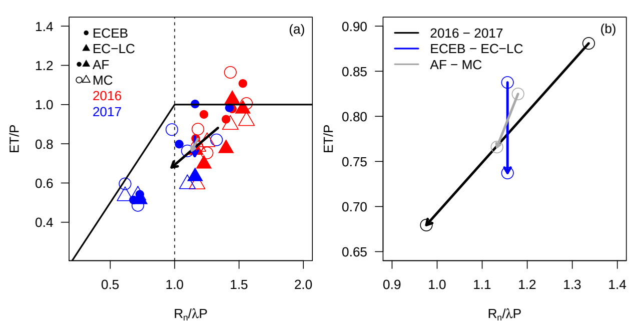


Figure 11. **(a)** Evapotranspiration index (~~∑~~ET/~~∑~~P) versus the radiative dryness index (~~∑ET_p~~R_n/~~∑~~λP) for both land-uses (AF: filled triangles and dots; MC: empty triangles and dots), both set-ups (ECEB: dots; EC-LC: triangles) and both years (2016: red; 2017: blue). The bold black line describe regions of an energy limitation (~~ET_p~~R_n/λP<1) and a water limitation (~~ET_p~~R_n/λP>1). The arrows indicate mean trends of ET for the effect of different years (black arrow), different methods (blue arrow) and different land-uses (grey arrow). **(b)** Trends of the mean evapotranspiration index (ET/P) versus the mean radiative dryness index (R_n/λP) for the effect of different years (black), different methods (blue) and different land-uses (grey) extracted from figure (a).

1993). The canopy resistance depends linearly on the aerodynamic resistance and is part of the first term of Eq. (A14). If the first term on the right hand side of Eq. (A14) is high, the canopy resistance is high and evapotranspiration is controlled by atmospheric processes. Whereas if the aerodynamic resistance is low the second term on the right hand side of Eq. (A14) dominates, i.e., ET is mainly controlled by the plants physiology.

Mean aerodynamic resistances, r_{ah}, were lower at the AF ~~plots~~ systems compared to the MC ~~plots~~ systems (Fig. 12). We ~~derived aerodynamic resistances with LE from EC-LC. In detail, r_{ah} was lower at the AF compared to the MC plot by 46.4 % at Dornburg, 46.1 % at Forst, 57.7 % at Mariensee, 44.1 % at Reiffenhausen, and 50 % at Wendhausen. The magnitude of r_{ah} at both the AF and the MC plots were comparable to agricultural fields and short rotation plantations (Lindroth, 1993; Schmidt-Walter et al., 2014). Our observations agree with our expectations and~~ interpret this as an effect of the higher roughness incurred by the higher tree alleys ~~led to a decreased aerodynamic resistance at the AF plot~~ compared to the MC ~~plot. Exemplary,~~ system. As an example we derived an aerodynamic resistance for two different canopy heights of 1 m and 5 m. We assumed a constant wind speed, u = 2 $\mathrm{m\,s^{-1}}$, universal constants for momentum ψ_m = 0.9 and heat ψ_h = 0.4, a measurement height z of 10 m and a displacement height d of ~~7 m~~0.7 m and 3.5 m for a canopy height of 1 m and 5 m, respectively. We derived a roughness length for momentum and heat of ~~0.5 m and 0.05~~ 0.1 and 0.01 m for a canopy height of ~~5 m and 0.1 and 0.01~~ 1 m and of 0.5 m and 0.05 m for a canopy height of ~~1~~ 5 m. Subsequently, we arrived at an aerodynamic resistance of ~~10.3~~ 41.5 $\mathrm{s\,m^{-1}}$ for a canopy height of ~~5 m and 41.5~~ 1 m and of 10.3 $\mathrm{s\,m^{-1}}$ for a canopy height of ~~1~~ 5 m. Thus, ~~a decrease~~ an increase in canopy height of 4 m led to ~~an increase~~ a decrease in aerodynamic resistance of 75.2 %.

The relationship between half-hourly evapotranspiration rates and the canopy resistance at ~~our~~ the sites followed an exponential function (Fig. 12). The differences between the mean canopy resistances at the AF and the MC ~~plots~~ systems were much smaller than differences in mean aerodynamic resistances at the AF and the MC ~~plots. We found higher mean canopy resistances at the AF than at the MC plot of 2.8 % at Dornburg and 7.4 % at Mariensee. Lower mean canopy resistances at the AF than at the MC plot of 5.1 % were found at Forst, 3.7 % at Reiffenhausen and 42 % at Wendhausen~~systems. This suggests that the AF and the MC systems behave in a similar way from a plant physiological point of view, regarding the stomatal control of both the trees and the crops. ~~The small differences in canopy resistance at the two land-uses are a good indication for small differences between half-hourly evapotranspiration rates at the AF and the MC plots. Annual sums of ET (from EC-LC for 2016) across sites for both land-uses were 365±28 for AF sites and 345±39 for MC sites and were not significantly different (p = 0.354). Annual sums of ET averaged for the years 2016 and 2017 were also not significant (p=0.7) with a mean annual sum of ET of 370±38 for AF sites and 361±51 for MC sites. We conclude that the cultivation of fast growing trees and crops on the same piece of land does not have a significant effect on annual sums of ET, rejecting our initial hypothesis.~~

~~The agroforestry systems investigated in~~ In the current study ~~had a sustainable water-use strategy, indicated by small differences in the~~ differences between annual sums of ET ~~between~~ over AF and MC ~~sites~~were small. Effects of ~~agroforestry~~ AF on evapotranspiration rates are mostly attributed to a small region next to the tree strips (Kanzler et al., 2018), the quiet zone. There, the reduction of wind velocity and incident radiation is strongest and this causes a reduction of evapotranspiration. The quiet zone extends to roughly 4 to 12 times the tree height (Nuberg, 1998). The quiet zone changes to the wake zone, where the wind velocity increases and light is no longer limited, hence, evapotranspiration increases towards the centre between tree strips (Kanzler et al., 2018). As a result, both positive and negative effects of trees on evapotranspiration lower ET in the quiet zone and higher ET in the wake zone might compensate each other on system-scale, leading to ET over AF comparable to ET over MC. A similar effect occurs when evapotranspiration ET is measured over a whole agroforestry AF system with e.g. the EC method (Baldocchi, 2003). EC measurements integrate over a larger area and small scale differences attributed to the quiet zone in between tree strips can not be detected. Hence, differences can be small.

The effect of trees on wind velocity and evapotranspiration reduction is strongest for shorter tree strip distances, hence, a high relative area covered by trees (Böhm et al., 2014; Nuberg, 1998). At our sites, the relative area covered by trees is small for the larger sites (e.g. Dornburg, Forst, Mariensee and Wendhausen) (Table 1) and varies between 6 and 12 . The distances between the tree strips varies between 24 and 96 m. Böhm et al. (2014) argued that a distance larger than 50 m is already too wide for efficient wind velocity protection and the associated evapotranspiration reduction. For larger distances between tree strips, the generated turbulent kinetic energy within the AF system might be equal or even larger than at the MC system (McNaughton, 1988), which causes higher ET over AF relative to a MC system. At the smallest site (), Reiffenhausen, the relative area covered by trees amounts to 72 . At this site our measurements reveal slightly lower annual sums of ET over AF relative to MC (Fig. 10). The AF system is in the south-west and north-west limited by a poplar and willow short rotation coppice plantation, directly within the footprint of the tower (Fig. 3 d). The observations from Reiffenhausen agree with investigations on water use of short rotation coppices in the Czech Republic (Fischer et al., 2013) and in Belgium (Zenone et al., 2015). Hence, the AF system in Reiffenhausen seems to behave more like a SRC.

3.6 Uncertainty and limitations of ET measurements over AF

As outlined in the previous section, differences in annual sums of ET between the different land-uses were smalland not significant. Besides the discussed ecological reasons, we are aware of measurement errors due to the heterogeneous terrain (Foken, 2008b). The most critical assumptions of the eddy covariance method are horizontally homogeneous terrain and steady state ambient conditions (Foken et al., 2006; Foken, 2008b). It is assumed that the heterogeneities generate turbulent motions of longer time scale than the commonly applied averaging period of half an hour. This is also strongly connected to horizontal advection, commonly not properly represented in eddy covariance flux measurements. Foken et al. (2006) noted that the eddy covariance method is the most accurate method with errors between 5 and 10 %, depending on the turbulent conditions. The errors are higher during nighttime, due to limited turbulent conditions, causing a common flux underestimation (Aubinet et al., 2010). But during night especially ET is small and the effect of high errors are small, compared to daytime conditions when ET is high.

For our the low-cost eddy covariance set-up we anticipate higher errors compared to direct EC, due to the limited time response of the thermohygrometer and subsequently higher spectral correction factors (Markwitz and Siebicke, 2019). We found that the effect of heterogeneity on ET is less important for EC-LC than the effect of different measurement heights (Markwitz and Siebicke, 2019). For a measurement height of 3.5 m, we found a latent heat flux underestimation compared to direct EC, and for a measurement height of 10 m, we found a slight latent heat flux overestimation (Table 4). At lower height the contribution of small and high-frequency fluctuations to the energy spectrum is higher. Due to the limited time response of the thermohygrometer between 1.9 and 3.5 seconds (Markwitz and Siebicke, 2019), the high-frequency eddies can not be adequately detected and the signal losses are higher.

In contrast, ET obtained by the ECEB set-up ET_{ECEB} might be affected by greater errors than EC-LCET_{EC-LC}, due to multiple error sources inferred from each of the energy balance components, the assumption of a fully closed energy balance and resulting inaccuracies from the energy balance residual partitioning. For ET obtained by ECEB the ECEB set-up the heterogeneity of the landscape has a larger impact than for the EC-LC set-up, such as net radiation and ground heat flux measurements are not representative for the whole landscape(Section ?? and Figure ??).

Although errors for ET measurements with the respective set-ups can be large on a half-hourly time scale, for annual sums of ET, the errors often compensate each other and are small in relation relative to the measured signal (Hollinger and Richardson, 2005). As an example, we calculated the random error uncertainty after Hollinger and Richardson (2005) for latent heat fluxes from Dornburg AF for 2016. The larger the integration time (hourly, daily and monthly), the smaller the random error. The magnitude of the random error was about 2.3 % (median over n = 9) of the flux magnitude for monthly averages, 11.55 % (n = 254) for daily averages and 34.5 % (n = 12191) for hourly averages. Hence, the random error for annual sums would be even smaller.

4 Conclusions

The main objective of the current work was to investigate the effect of agroforestry AF on evapotranspiration in comparison to conventional agriculture monoculture agriculture without trees. We performed ET evapotranspiration measurements at multiple sites, requiring methods of low cost and low maintenance. Therefore we measured evapotranspiration for two consecutive years obtained by a low-cost eddy covariance set-up and an eddy covariance energy balance set-up.

In the first part of this work paper we investigated the performance of the measurement set-ups. In comparison with direct eddy covariance measurements the low-cost eddy covariance set-up captured the temporal variability in half-hourly ET rates with high coefficients of determination during a comparison measuring campaign. The ECEB set-up also represented the diel cycle of ET, but was characterized by more scatter. We therefore conclude that the EC-LC set-up is a viable alternative compared to conventional eddy covariance set-ups, as the set-up represents ET of the underlying ecosystem more accurately than the ECEB set-up.

In the second part of this paper work we focused on the question if agroforestry AF systems have higher water losses to the atmosphere via ET compared to monoculture systems. Our results showed that differences in ET between AF and MC were not significantsmall. Instead, we found significantly higher evapotranspiration indices during a drier than normal year compared to a wet year across sites and methods. This shows that the potentially small effect from the trees on ET was overlaid by the effect of local climatic conditions. In addition, we found a similar plant physiological response of the AF and the MC systems, characterized by small differences between canopy resistances.

Overall, we conclude that the inclusion of tree strips into the agricultural landscape has not resulted in ~~significant~~ higher water losses to the atmosphere via ET and agroforestry can be a land-use alternative to ~~conventional agriculture~~ monoculture agriculture without trees.

Data availability. All data used for the figures in this manuscript will be provided after final acceptance for publication.

Author contributions. CM designed and performed the field work, analysed the data and has written the current manuscript. AK and LS wrote the project scientific proposal, acquired the funding as part of the BonaRes SIGNAL consortium, and contributed to field work and analysis. All authors contributed to the discussion and manuscript writing.

Competing interests. The authors declare no competing interests.

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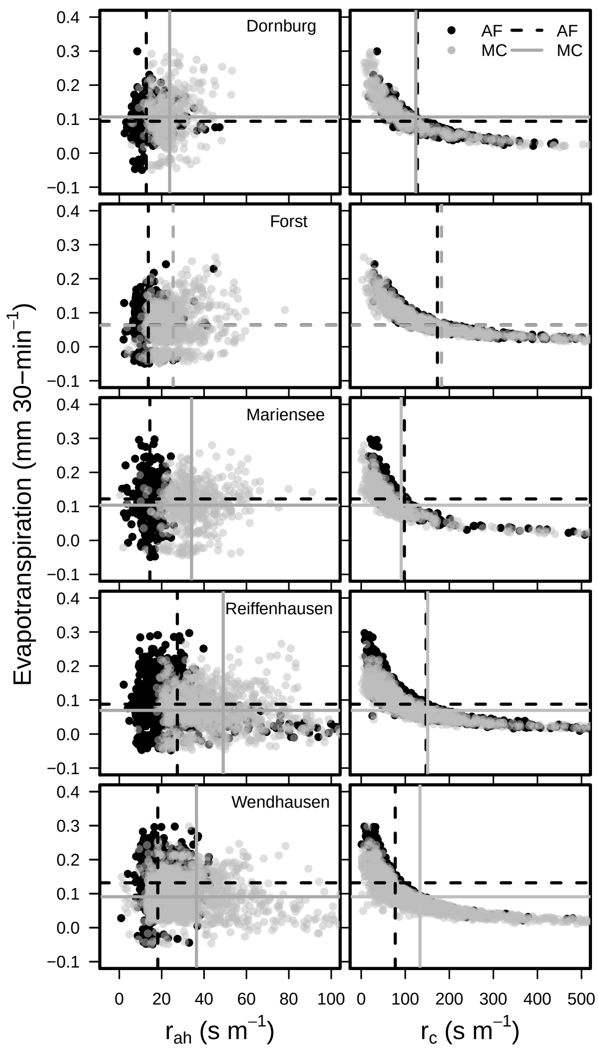

Figure 12. Half-hourly evapotranspiration rates from EC-LC $\mathrm{ET_{EC-LC}}$ versus aerodynamic resistance, r_{ah} (left), and canopy resistance(right) for Dornburg, (a), Forst, (b), Mariensee, (c), Reiffenhausen, r_c (dright), and Wendhausen, (e)for all sites. The dashed grey line corresponds to the mean aerodynamic and canopy resistance and evapotranspiration at the AF plot system and the dashed black line corresponds to the mean aerodynamic and canopy resistance and evapotranspiration at the MC plot system at the specific site. Only data corresponding to ideal ambient conditions are shown, e.g. a global radiation, $R_G \geq 400\ \mathrm{W\,m^{-2}}$, a wind speed, u $\geq 1\ \mathrm{m\,s^{-1}}$ and a vapour pressure deficit, VPDD = 1±0.3 kPa (Schmidt-Walter et al., 2014).

Appendix A: Derivations

A1 Half-hourly ET rates and soil storage flux

Half-hourly evapotranspiration rates in units of $\mathrm{mm\,30\,min^{-1}}$ were calculated from LE as

$$ET = \frac{LE_{ECEB}(\mathrm{J\,kg^{-1}\,s^{-1}})}{L(\mathrm{J\,kg^{-1}})} \cdot 1800(\mathrm{s\,30\,min^{-1}}) \cdot \frac{1}{\rho_{H_2O}}(\mathrm{m^3\,kg^{-1}}) \cdot 1000\,\mathrm{mm\,m^{-1}} \tag{A1}$$

with L ($\mathrm{J\,kg^{-1}}$) the latent heat of vaporization (Dake, 1972) depending on air temperature T (°C)

$$L = (2.501 - 0.00237\,T) \cdot 10^6, \tag{A2}$$

and $\rho_{\mathrm{H_2O}} = 1000\,\mathrm{kg\,m^{-3}}$ the density of liquid water.

The soil heat storage term has a major contribution to the unclosed energy balance (Foken, 2008a) and the magnitude of the soil heat storage is comparably larger than the other storage terms, i.e. the photosynthesis flux, the crop enthalpy change, the air enthalpy change, the canopy dew water enthalpy change and the atmospheric moisture change (Jacobs et al., 2008). We used the ground heat flux, G, from the ground heat flux measurements, $\mathrm{G_{HFP}}$ ($\mathrm{Wm^{-2}}$), at the sites and calculated the soil heat storage between the soil heat flux plate and the soil layer above following Liebethal and Foken (2007) as

$$G = G_{HFP} + \int_{z=-0.05\,m}^{0\,m} c_v \frac{\partial T}{\partial t} dz \tag{A3}$$

The soil heat storage (second term on the right hand side of Eq. (A3)) consists of the vertical integral of the change of temperature over time at depth z = 0.02 m. c_v is the volumetric heat capacity of the soil, calculated from the soil components, i.e. organic, mineral and water and their respective heat capacities. Soil texture and bulk densities are summarized in Table A2 and were provided by Göbel et al. (2018) and Marcus Schmidt (pers. comm., Georg August University of Goettingen, Buesgen Institute, Soil Science of Tropical and Subtropical Ecosystems). Gaps in soil storage data were filled according to a multiple linear regression with soil storage versus net radiation and ground heat flux. The multiple linear regression fitting parameter were derived from records when the soil storage, the net radiation and the ground heat flux were available at the same time.

A2 Water vapour mole fraction $\mathrm{C_{H_2O_v}}$ from the thermohygrometer

The derivation of the water vapour mole fraction $\mathrm{C_{H_2O_v}}$ from relative humidity, air temperature and air pressure from the low-cost thermohygrometer was also presented in Markwitz and Siebicke (2019) and is given in this section.

The water vapour mole fraction, $\mathrm{C_{H_2O_v}}$, was derived from the definition of the specific humidity, q, as the quantity of water vapour per quantity of moist air. The latter two quantities were expressed as the density of water vapour, $\rho_{\mathrm{H_2O_v}}$, and moist air,

ρ_m, respectively. The density of moist air is defined as the sum of the density of dry air, ρ_d, and the density of water vapour.

$$q = \frac{\rho_{H_2O_v}}{\rho_m} = \frac{\rho_{H_2O_v}}{\rho_d + \rho_{H_2O_v}} \tag{A4}$$

We then replaced the density of water vapour and the density of dry air in Eq. (A4) as per Eqs. (A5) and (A6), respectively,

$$\rho_{H_2O_v} = \frac{C_{H_2O_v} \cdot M_{H_2O_v}}{V_m} \tag{A5}$$

$$\rho_d = \frac{p - e_a}{R_d \cdot T} \tag{A6}$$

with the molar mass of water vapour, $\mathrm{M_{H_2O_v}} = 18.02\,\mathrm{g\,mol^{-1}}$, the molar volume of air

$$V_m = \frac{\Re \cdot T}{p}\,(\mathrm{m^3\,mol^{-1}}), \tag{A7}$$

the universal gas constant, $\Re = 8.314\,\mathrm{J\,mol^{-1}K^{-1}}$, and the specific gas constant of dry air, $\mathrm{R}_d = 287.058\,\mathrm{J\,kg^{-1}\,K^{-1}}$.

Solving Eq. (A4) for $\mathrm{C_{H_2O_v}}$ leads to the water vapour mole fraction

$$C_{H_2O_v} = \frac{q\,\Re\,(p - e_a)}{p\,M_{H_2O_v}\,R_d(1-q)}. \tag{A8}$$

The specific humidity in Eq. (A8) was calculated as a function of relative humidity, temperature and air pressure measurements from the thermohygrometer:

$$q = 0.622 \cdot \frac{e_a}{p} \tag{A9}$$

The actual vapour pressure, $\mathrm{e_a}$ (kPa), in Eq. (A9) was calculated from an approximation of the saturation vapour pressure, $\mathrm{e_*(T)}$ (Stull, 1989) and from relative humidity, RH,

$$e = \frac{RH \cdot e_*(T)}{100} \tag{A10}$$

$$e_*(T) = 0.6112 \exp\left(\frac{17.67\,T}{(T + 273.15) - 29.66}\right) \tag{A11}$$

A3 Canopy resistance

The Penman-Monteith equation for evapotranspiration of a canopy (Monteith, 1965) is

$$LE = \frac{s(R_N - G) + c_p\,D\,g_{ah}}{s + \gamma(1 + g_{ah}/g_c)} \tag{A12}$$

with the vapour pressure deficit, $\mathrm{D} = \mathrm{e}_*(\mathrm{T}) - \mathrm{e_a}$ (hPa), the heat capacity at constant pressure, $c_p = 1005\ \mathrm{J\,(kg\,K)^{-1}}$ and the psychrometer constant, $\gamma = (c_p P_A)/(L\,0.622)$.

The slope of the saturation vapour pressure curve, s, is

$$s = \frac{\varepsilon L q_{sat}}{R_v T} \tag{A13}$$

with $\varepsilon = 0.622$ and the specific humidity at saturation, $q_{sat} = \varepsilon e_*(T)/P_A$ as a function of temperature.

Rearranging Eq. (A12) yields the canopy resistance, r_c $(\mathrm{s\,m^{-1}})$,

$$r_c = \frac{1}{g_c} = \frac{s/\gamma + 1}{g_{ah}}\left[\frac{s/\gamma(R_N - G)}{(s/\gamma + 1)LE} - 1\right] + \frac{c_p D}{\gamma LE} \tag{A14}$$

The aerodynamic conductance for heat is

$$g_{ah} = \frac{1}{r_{ah}} = \frac{\kappa^2 u}{\left(\ln\left(\frac{z-d}{z_{0m}}\right) - \psi_m(\zeta)\right)\left(\ln\left(\frac{z-d}{z_{0h}}\right) - \psi_h(\zeta)\right)} \tag{A15}$$

with the von Karman constant, $\kappa = 0.4$, the horizontal wind velocity, u $(\mathrm{m\,s^{-1}})$, the measurement height, z (m), the displacement height, d (m), estimated as 70 % of the canopy height, the roughness length for momentum transport, $\mathrm{z_{0m}}$, estimated as 10 % of the canopy height and the roughness length for heat transport, $\mathrm{z_{0h}}$, estimated as 10 % of $\mathrm{z_{0m}}$. $\psi_\mathrm{m}(\zeta)$ is the universal function for momentum and $\psi_\mathrm{h}(\zeta)$ is the universal function for heat. $\psi_\mathrm{m}(\zeta)$ and $\psi_\mathrm{h}(\zeta)$ depend on atmospheric stability with the stability parameter $\zeta = (\mathrm{z} - \mathrm{d})/\mathrm{L}$, including the Monin-Obukhov length, L. ψ_m and ψ_h were calculated as

$$\psi_m(\zeta) = \begin{cases} 2\ln[(1+x)/2] + \ln[(1+x^2)/2] & \text{for } \zeta < 0 \\ -2\arctan(x) + \pi/2 & \\ & \\ -5\zeta & \text{for } \zeta \geq 0 \end{cases} \tag{A16}$$

$$\psi_h(\zeta) = \begin{cases} 2\ln[(1+x^2)/2] & \text{for } \zeta < 0 \\ -5\zeta & \text{for } \zeta \geq 0 \end{cases} \tag{A17}$$

with $\mathrm{x} = (1 - 16\zeta)^{1/4}$ (Bonan, 2016; Businger et al., 1971; Stull, 1989).

Appendix B: Tables

Table A1. Temporal ~~extend~~ extent of the EC measurement campaigns.

Site	Campaign period
Dornburg MC	16 June to 14 July 2016
Donburg AF	14 July to 12 August 2016
Reiffenhausen AF	12 August to 14 September 2016
Wendhausen	03 May to 02 June 2017
Forst	08 June to 08 July 2017
Mariensee	21 July to 19 September 2017

Table A2. ~~Mean air temperature, T_A, vapor pressure deficit, VPD, global radiation, R_G~~ Site specific soil characteristics, ~~and~~ with the ~~cumulative precipitation, P,~~ soil texture being representative for the ~~respective site and campaign period~~ top soil column of 0.3 m.

~~Site T_A () P () VPD () R_G~~ The bulk density is representative for the top soil column of 0.05 m. Data provided by Göbel et al. (2018) and Marcus Schmidt (pers. comm., Georg August University of Goettingen, Buesgen Institute, Soil Science of Tropical and Subtropical Ecosystems) ~~Dornburg AF 19.0 57.1 6.41 200.7 Dornburg MC 18.6 2.1 7.35 212.6 Forst AF 21.4 18.9 12.02 358.8 Forst MC 21.2 14.8 11.88 371.5 Mariensee AF 18.54 40.6 6.2 258.9 Mariensee MC 16.93 163.5 4.7 172.8 Reiffenhausen AF 19.31 26.3 8.02 219.1 Wendhausen AF 16.6 48.6 5.4 235.0 Wendhausen MC 15.5 90.7 5.2 239.9~~

~~Site specific soil characteristics, with the soil texture being representative for the top soil column of 0.3 m. The bulk density is representative for the top soil column of 0.05 m. Data provided by Göbel et al. (2018) and Schmidt et al. (unpublished data).~~ .

Site	Clay content (%)	Sand content (%)	Bulk density ($kg\,m^{-3}$)
Dornburg AF	20.5	3.75	1.22
Dornburg MC	38	10.75	1.19
Forst AF	7	60.75	1.3
Forst MC	9.5	66.75	1.28
Mariensee AF	11.75	48	–
Mariensee MC	31.67	54.33	1.28
Reiffenhausen AF	23.75	31.5	1.28
Reiffenhausen MC	22.75	49.75	1.28
Wendhausen AF	35	18.25	1.085
Wendhausen MC	44.5	27	0.89

Appendix B: Figures

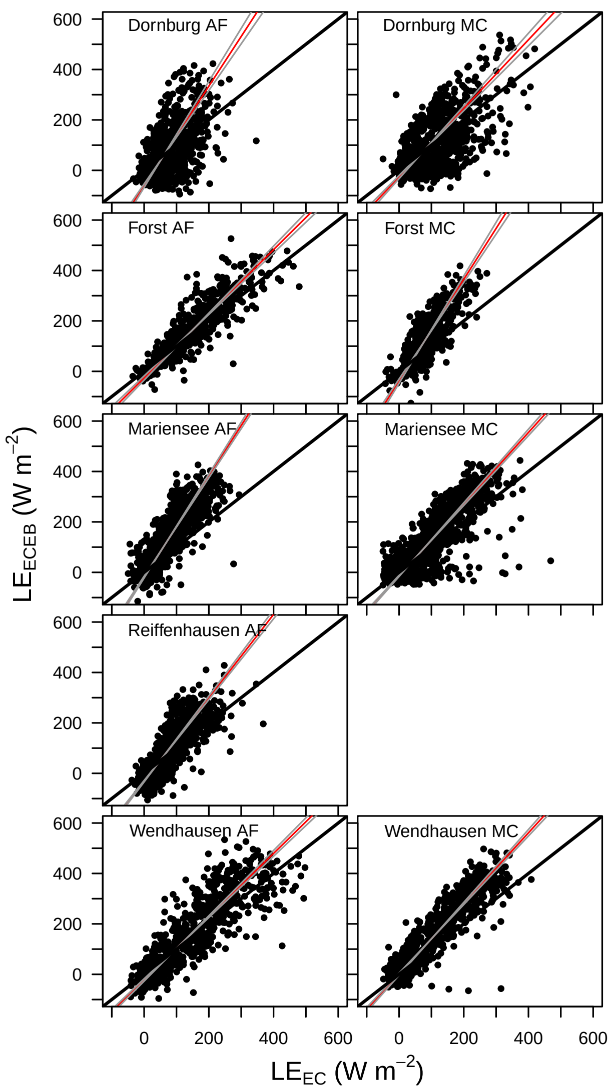

Figure A1. Scatter plot of ~~LE from ECEB~~ LE_{ECEB} versus ~~EC at Dornburg agroforestry, (a), Dornburg monoculture, (b), Forst agroforestry, (c), Forst monoculture, (d), Mariensee agroforestry, (e), Mariensee monoculture, (f), Reiffenhausen agroforestry, (g), Wendhausen agroforestry, (h), and Wendhausen monoculture, (i)~~LE_{EC} for all sites. The red line denotes the best fit line with grey lines the ±2.5 % confidence interval lines and the solid black lines corresponds to the 1:1 line. Data from Reiffenhausen MC are missing due to the unavailability of a campaign.

~~Box-plot of the annual summed ET, a, and the evapotranspiration index, b, for 12 FLUXNET sites, e.g., Gebesee, “DE-Geb”, Klingenberg, “DE-Kli”, Selhausen, “DE-Seh”, Hainich, “DE-Hai”, Willow Creek, “US-WCr”, Lackenberg, “DE-Lkb”, Oberbärenburg,~~

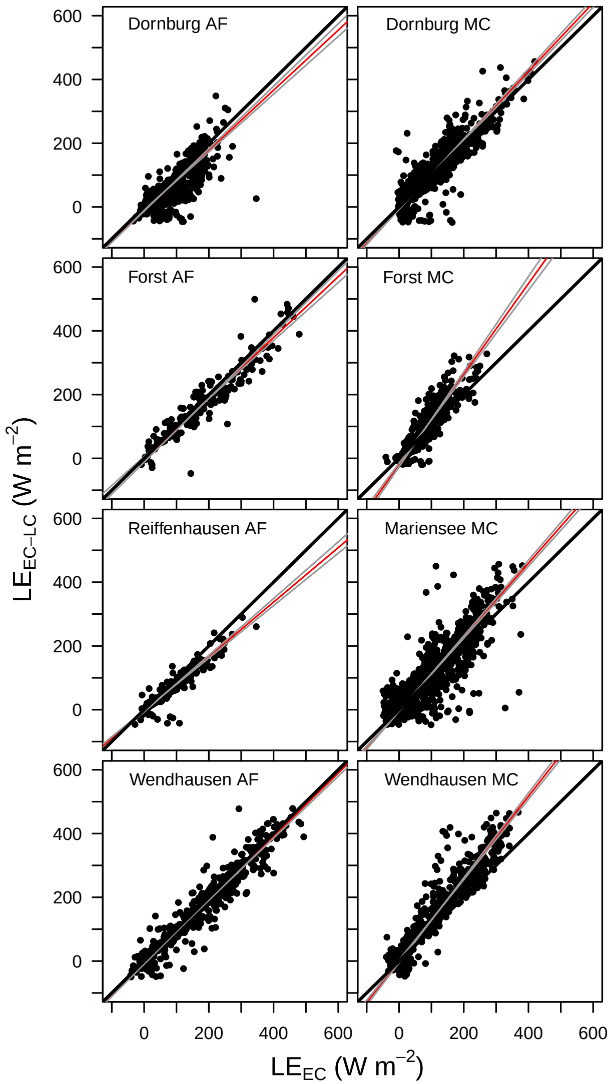

Figure A2. Scatter plot of LE from EC-LC LE_{EC-LC} versus EC at Dornburg agroforestry, (a), Dornburg monoculture, (b), Forst agroforestry, (c), Forst monoculture, (d), Reiffenhausen agroforestry, (e), Mariensee monoculture, (f), Wendhausen agroforestry, (g), and Wendhausen monoculture, (h)LE_{EC} for all sites. The red line denotes the best fit line with grey lines the ±2.5 % confidence interval lines and the solid black lines corresponds to the 1:1 line. Data from Reiffenhausen MC are missing due to the unavailability of a campaign and LE_{EC-LC} from Mariensee AF is missing due to sensor malfunctions.

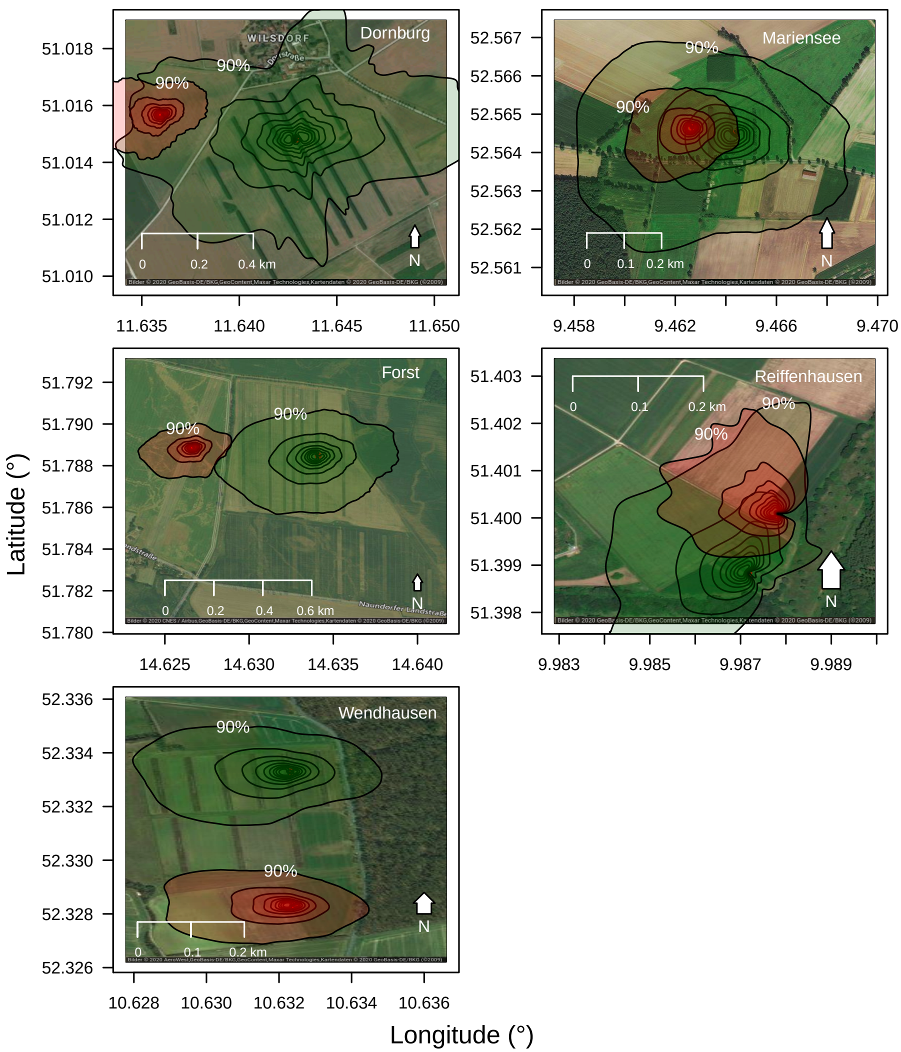

Figure A3. Flux footprint climatology for ~~Dornburg, (a), Mariensee, (b), Forst, (c), Reiffenhausen, (d),~~ all sites and ~~Wendhausen, (e), for both~~ all ~~data~~ available data during the years 2016 and 2017. Green shaded footprints correspond to the agroforestry ~~plot~~ system and red shaded footprints correspond to the monoculture ~~plot~~system. For the analysis only daytime data were used ($R_G > 20$ Wm−2). Aerial photographs originate from Google maps/ Google earth ©Google 2020.

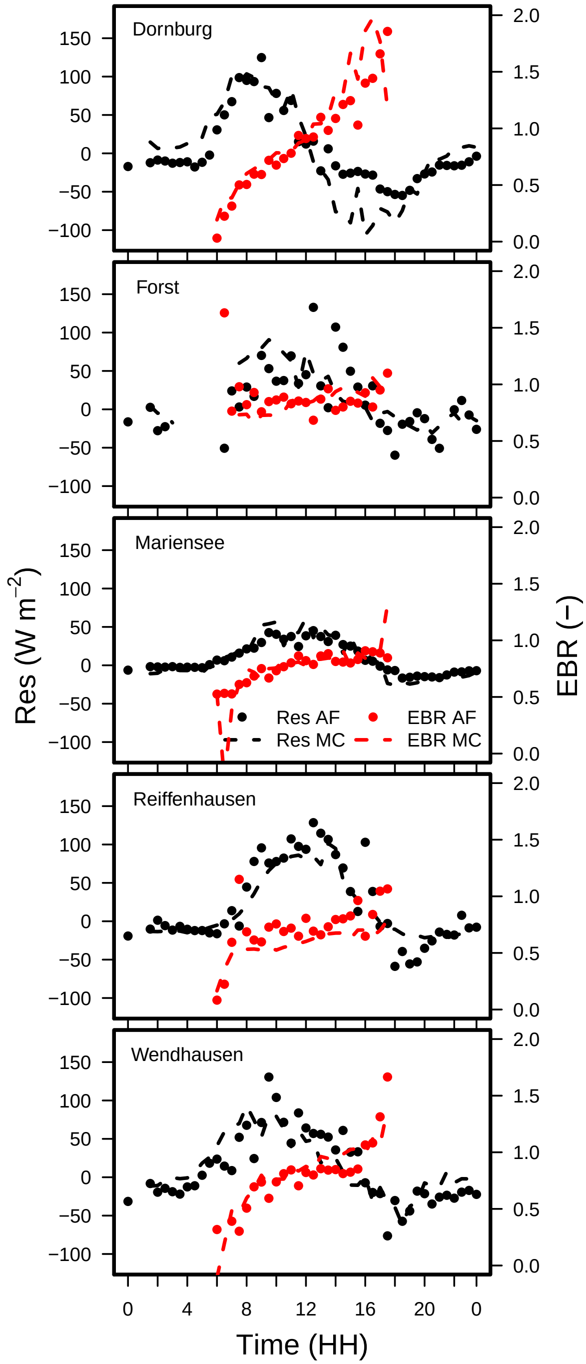

Figure A4. Daily median Median diel cycle of the energy balance ratio (EBR) and diurnal cycle of the residual energy at Dornburg, (a), Forst, (b), Mariensee, (c), Reiffenhausen, (d), and Wendhausen, (e), for the agroforestry (AF) and the monocultural plots (MC) separatelysystems at all sites. The latent and sensible heat flux LE was calculated following obtained by EC-LC. Data from Mariensee AF are from 23 March 2016 to 20 November 2016 and at Reiffenhausen MC the low-cost eddy covariance set-upanalyses are based on data collected from 07 April 2016 to 31 December 2016, because no data were available during the campaigns.

~~"DE-Obe", Tharandt, "DE-Tha", Grillenburg, "DE-Gri", Rollesbroich, "DE-RuR", Horstermeer, "NL-Hor", and Anklam, "DE-Akm". The number of years used for the analysis is written at the bottom of the plot.~~

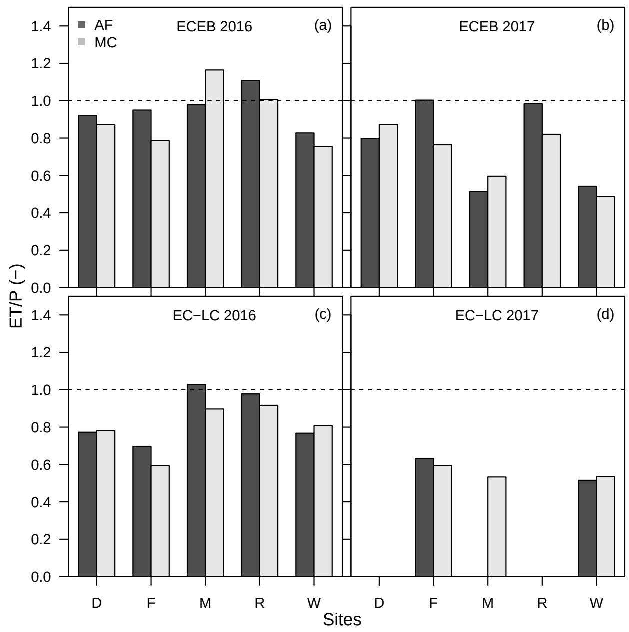

Figure A5. Bar plot of the evapotranspiration index for the ECEB method for the years 2016, a, and 2017, b, and for the EC-LC method for 2016, c, and 2017, d, for sites, e.g., Dornburg, "D", Forst, "F", Mariensee, "M", Reiffenhausen, "R", and Wendhausen, "W". The dashed line indicates a evapotranspiration index of one. Evapotranspiration indices for Dornburg AF and MC, Mariensee AF, Reiffenhausen AF and MC in 2017 are missing due to instrument malfunctions.

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