Effects of agricultural management on measurements, prediction, and partitioning of evapotranspiration in irrigated grasslands.

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Abstract

Irrigation is an important component of the hydrologic cycle in agricultural ecosystems, affecting both quantity and quality of surface and ground water. Well-managed irrigation involves balancing irrigation with water consumption by evaporation and transpiration (collectively evapotranspiration), maximizing ecosystem water-use efficiency and minimizing drainage. Here we compare rates of actual crop evapotranspiration (ET_C) measured by eddy covariance with reference evapotranspiration (ET_0) calculated from meteorological variables for two irrigated ryegrass systems in central South Island, New Zealand between June 2011 and March 2013. The sites were similar in climate, but contrasted in management: one grazed by dairy cattle and the other harvested annually for seed. Over the first year of measurements, cumulative ET_C was very similar at the two sites, totalling 791 and 819 mm for the dairy pasture and seed crop respectively, although temporal patterns of partitioning of ET_C amongst evaporation and transpiration differed as a result of management activities. Responses of ET_C to global radiation, temperature and vapour pressure deficit were all similar during active growing season periods. Differences between the two sites were observed at the end of the second measurement season, when irrigation was ceased in the seed crop prior to final harvest and ET_C was reduced compared to ET_0. As a result, cumulative ET_C was 13% greater for the dairy pasture at the end of the study period.

Key words: eddy covariance; evaporation; water-use efficiency; grazing; irrigation; *Lolium perenne*

1. Introduction

Evapotranspiration is an important component of ecosystem water balance, typically equalling 50% or more of precipitation (Williams et al., 2012). Efficient agricultural water management depends upon the precise balance of irrigation and precipitation with water consumption by actual crop evapotranspiration, ET_C. The consequences of unbalanced irrigation practices include plant water deficits, which reduce crop yields (Zwart and Bastiaanssen, 2004), and excessive soil drainage, which may increase nutrient leaching rates (Martin et al., 1994). Thus, a good understanding of controls on evapotranspiration is required for efficient management of water resources.

Available energy from net radiation and atmospheric demand for water vapour are the primary drivers of ET_C. Numerous models, which range in complexity, have been developed for predicting potential rates of evapotranspiration from meteorological data (Allen et al., 1998; Penman, 1948; Priestley and Taylor, 1972). However, these models are typically underpinned by the assumption of a well-watered reference crop and require correction in order to properly represent ET_C (Sumner and Jacobs, 2005). In particular, vegetation can be an important source of variation in rates of ET_C. Vegetation can influence ET_C through its effect on physical properties, such as available energy and albedo (Wang et al., 2012), surface properties, such as surface roughness (Monteith and Unsworth, 2013), and through direct stomatal control of transpiration (Jarvis and McNaughton, 1986).

In agricultural landscapes, management practices influence species composition, leaf area, plant nutrition and phenology, all of which may impact ET_C. Grazing of grasslands is a particularly widespread management practice, extending to 25% of the global land area (Asner et al., 2004). Grazing can lead to reduction in ET_C relative to ungrazed sites (Bremer et al., 2001; Frank, 2003; Miao et al., 2009; Wang et al., 2012), impacting catchment-scale water balance (Fatichi et al., 2014). However, this effect is not universal (Pronger et al., 2016; Rosset et al., 2001; Stewart and Verma, 1992) and changes in ET_C are difficult to link directly to grazing-induced changes in leaf area.

Within New Zealand, grazing systems are an important land use, with 5.7 Mha (21% of land area) of high-producing grassland used primarily for grazing and silage production (Ministry for the Environment, 2015). Increasingly, agricultural production has shifted from low-intensity, dryland farming to high-intensity grazing for dairy. The number of dairy cattle within New Zealand increased by 27% over the period 2005-2012 (Statistics New Zealand, 2013). Correspondingly, irrigated land area has increased by 17% over the same period to support additional productivity. The majority of this increase has occurred in the Canterbury region.

The objective of the current study is to determine the impact of two management practices common within the Canterbury region on measurement of ET_C in irrigated grasslands. We compare seasonal patterns and accumulation of ET_C and predictions of potential evapotranspiration from a dairy pasture subjected to rotational grazing with a ryegrass crop harvested annually for seed over the period June 2011 to March 2013. The response of ET_C to environmental drivers and variations in leaf area is also investigated. These measurements are essential for integrating management practices into predictions of ET_C and development of best-practice techniques for managing irrigation in response to daily and seasonal demand from ET_C. These data could also provide the basis for optimizing land-use within water-limited irrigation schemes.

2. Materials and Methods

2.1 Site description

Study sites selected for comparison were a dairy farm and crop farm located in the Canterbury Plains region, South Island, New Zealand. Both sites are on alluvial soils under similar climatic conditions. The dairy pasture site (43°40’26.61” S, 171°35’27.63” E, elevation: 309 m) was a high-producing, rotationally grazed mix of perennial ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*). Soils at the site are Lismore pallic firm brown (Typic Dystrustept) (Hewitt, 2010; Soil Survey Staff, 2006) with a field capacity of 0.28 m^3 m^{-3} and wilting point of 0.10 m^3 m^{-3} for the top 300 mm of soil (Landcare Research, 2016). The crop farm (43°58’14.25” S, 171°47’41.78”, elevation: 47 m) was planted in perennial ryegrass which was mowed to a height of approximately 150 mm each year in October and allowed to grow until February when it was harvested for seed. The site was also grazed by sheep or mowed periodically over the winter (May through September). Following the second harvest in February 2013, the site was sprayed with herbicide in preparation for a new crop. Soils at the site are Templeton typic immature pallic (Udic Haplustept) (Hewitt, 2010;

Soil Survey Staff, 2006) with a field capacity of 0.34 m^3 m^{-3} and wilting point of 0.17 m^3 m^{-3} (Landcare Research, 2016).

Over the measurement period, 11 June, 2011 to 4 March, 2013, mean daily air temperature was 8.6 and 9.1 °C for the pasture and crop sites, respectively. Mean incoming solar irradiance was 166 W m^{-2} for the pasture and 168 W m^{-2} for the crop site. The pasture site received approximately 30% more rainfall (Table 1), which is consistent with an East-West gradient in precipitation across the Canterbury region along which the sites are situated (Srinivasan and Duncan, 2011; Tait et al., 2006). Both sites were irrigated throughout the summer months (October through April) in order to minimize soil water deficits (Fig.1, Table 1). Irrigation amounts were similar, however the application method differed between the sites. A linear irrigator applied up to 60 mm d^{-1} of irrigation 3-5 times during the irrigation season for the seed crop. A central pivot irrigator was used in the dairy pasture, applying water at lower rates (<15 mm d^{-1}) more frequently (4-5 day return interval).

2.2 Micrometeorological measurements

The eddy covariance method was used to measure sensible (*H*) and latent heat (*LE*, energy equivalent of evapotranspiration) fluxes, as well as fluxes of CO_2 (Baldocchi et al., 1988). Each site was equipped with a sonic anemometer (CSAT-3, Campbell Scientific, Logan, UT USA) and open-path CO_2/H_2O analyser (LI-7500A, LI-COR, Lincoln, NE USA) mounted at 2.3 m height. Ancillary meteorological measurements included net radiation (CNR2, Kipp and Zonen, Delft, Netherlands), global radiation (LI-200, LI-COR, Lincoln, NE USA) and soil heat flux (HFP01SC, Hukseflux, Delft, Netherlands). Soil temperature (TCAV, Campbell Scientific, Logan, UT, USA) and volumetric water content (CS615, Campbell Scientific, Logan, UT USA) were measured at 100 mm soil depth. Precipitation and irrigation were measured by tipping bucket rain gauges located within and immediately outside the irrigator footprint.

Raw, 10 Hz 3-dimensional wind speed and CO_2/H_2O concentrations were processed to 30 min average fluxes using EddyPro processing software (v 5.2.1, LI-COR, Lincoln, NE USA). Corrections were applied for density fluctuations (Webb et al., 1980), high-frequency spectral losses (Moncrieff et al., 1997), sonic temperature (Schotanus et al., 1983), and anemometer misalignment (Wilczak et al., 2001) within the EddyPro software package.

Resultant 30-min fluxes were screened for physically unrealistic values (LE < -200 W m^{-2}, LE > 800 W m^{-2}, H < -500 W m^{-2}, H > 1000 W m^{-2}, CO_2 flux > 40 µmol m^{-2} s^{-1}, CO_2 flux < -40 µmol m^{-2} s^{-1}). Fluxes with poor signal quality from the infrared gas analyser (AGC > 50), typically caused by irrigation, rain or dew on the sensors, were removed. Quality tests for stationarity and turbulent development were also used as filter criteria (Mauder and Foken, 2004). Further outliers in the 30 min flux record were removed according to Papale et al. (2006), using a conservative spike threshold (z) of 5.5. Turbulence measurements from wind directions between 190° and 280° at the pasture site and between 165° and 250° at the crop site were compromised due to interference from the tower structure and sensor arrangement and were removed. Overall system performance was assessed by comparing turbulent energy fluxes (LE+H) with available energy measured by net radiometer. Half-hourly energy budget closure was 78 and 77% percent for the pasture and crop sites respectively (as estimated from the slope of linear regression), very similar to the 80% average closure reported for FLUXNET sites (Wilson et al., 2002).

Gaps in the LE, H and CO_2 flux time series due to either missing or poor quality data were filled following Falge et al. (2001). Briefly, missing values were filled from a look up table of measurements occurring under similar conditions of solar irradiance (±50 W m^{-2}), air temperature (±2.5° C) and vapour pressure deficit (D, ±5 hPa). Look up tables values were constructed from values within a window of 2 days initially, increasing incrementally to 5, 7 and 14 days to accommodate larger gaps. Gap-filling was implemented with the 'REddyProc' package in R version 3.1.1 (R Development Core Team, 2014). Gap frequencies for latent heat fluxes were 0.37 and 0.36 for the pasture and crop sites respectively.

Measured ET_C was compared to reference evapotranspiration (ET_0) calculated using the FAO-56 Penman-Monteith method (Allen et al., 1998):

$$ET_0 = \frac{0.408\Delta(R_N - G) + \gamma \frac{900}{T_A + 273} u_2 D}{\Delta + \gamma(1 + 0.34u_2)} \qquad (1)$$

where Δ is the slope of the saturation vapour pressure curve (kPa °C^{-1}), γ is the psychrometric constant (kPa °C^{-1}), R_N is the net radiation (MJ m^{-2} d^{-1}), G is the soil heat flux (MJ m^{-2} d^{-1}), u_2 is the wind speed at 2 m height, T_A is the air temperature (°C), and D is the vapor pressure deficit. Meteorological variables for calculating ET_0 were obtained from a network of meteorological stations used to project climate variables across New Zealand (Tait and Woods, 2007). The nearest climate station was within <1 km of each eddy covariance site. Hourly air temperature, humidity, solar radiation and wind speed were measured at 2 m height above a grass-covered reference surface. Soil evaporation (E_S) was simulated using a modified Priestley-Taylor function (Ding et al., 2013; Priestley and Taylor, 1972):

$$E_S = \alpha \frac{\Delta}{\lambda(\Delta+\gamma)} e^{-kLAI}(R_N - G) \qquad (2)$$

Where α is a scaling coefficient set to 1.26, λ is the latent heat of vaporization (MJ kg^{-1}), k is a light extinction coefficient estimated as 0.5 for grasslands (Zhang et al., 2014), LAI is the leaf area index, R_N is net radiation and G is soil heat flux. Leaf area was estimated based on literature values for pre- and post-grazing in New Zealand (Korte et al., 1982). For the pasture, distinct peaks in the CO_2 record due to animal respiration and reduction in photosynthetic CO_2 uptake following leaf area removal were used to mark grazing events (Hunt et al., 2014). Immediately post-grazing, leaf area was set to 1 m^2 m^{-2}. Leaf area was allowed to increase as a linear function of accumulated gross primary production:

$$LAI = 0.01 \sum_{i=0}^{n} GPP_i + 1 \qquad (3)$$

where GPP is the daily gross primary production partitioned from the CO_2 flux record according to Reichstein et al. (2005) on the n^{th} day since a grazing event. This function was developed such that peak leaf area reached approximately 5-6 m^2 m^{-2} between summer grazing events. The same function was used to predict leaf area in the crop farm. It was assumed that mowing and harvest reduced leaf area in the crop farm to a similar extent as grazing (1 m^2 m^{-2}), and leaf area was allowed to increase to a maximum value until harvest each February. Crop leaf area was limited to 6 m^{-2} m^{-2}, similar to the maximum value used for the pasture (Fig.2). These values agree well with the maximum LAI of 6.7

and 6.6 $m^2\ m^{-2}$ obtained for the pasture and crop sites respectively using the MOD15 product of MODIS (ORNL DAAC, 2008).

2.3 Statistical Analyses

Linear regression was used to determine the capability of ET_0 for predicting ET_C at the two sites. Likewise, regressions of daily ET_C and ET_C/ET_0 against estimated *LAI*, net CO_2 flux and partitioned *GPP* were used to assess the impact of management events (i.e. harvest and grazing) on ET_C. Potential evapotranspiration deficit (ET_0 – [precipitation + irrigation]) was used an indicator of the water status of the two sites. Ecosystem water-use efficiency, defined as GPP/ET_C, was also compared for the two sites. Likewise, crop water-use efficiency, defined as $GPP/(ET_C - E_S)$ was compared.

3. Results and Discussion

3.1 Actual evapotranspiration

Over the first year of measurement (11 June 2011 – 10 June 2012), ET_C was 791 and 829 mm for the pasture and ryegrass seed crop sites, respectively. These values compare well with previous estimates of ET_C for ryegrass systems in New Zealand of 759-817 mm measured by eddy covariance in North Island dairy pastures (Kirschbaum et al., 2015; Pronger et al., 2016) and 792 mm measured in a nearby Canterbury dairy pasture by water balance residual from drainage lysimeters (Duncan et al., 2016). While crop ET_C exceeded the pasture water loss by 5% during the first year, pasture ET_C was 37% greater during the second partial year largely as a result of low ET_C following final harvest of the ryegrass crop and the cessation of irrigation (Fig. 3). Over this fallow period the total crop ET_C was only 28% of pasture ET_C. During vegetated periods, both seasonal and diurnal patterns of ET_C were remarkably similar for the two sites, despite different management regimes (Figs.3 and 4). In addition, the response of ET_C to solar irradiance, temperature, and vapour pressure deficit was nearly identical for the two sites (Fig. 5). Although, the response of ET_C to radiation was slightly lower during the second measurement season, possibly as a result of the period immediately pre-harvest when the seed crop was drying.

Frequent grazing events in the dairy pasture resulted in rapid cycles of regrowth, during which time *LAI* was estimated to vary between 1-6 m^2m^{-2} (Fig. 2). Although these estimates involved assumptions of maximum and minimum *LAI* based on literature values for pasture and supported by remote sensing estimates, timing of grazing and rate of accumulation of *LAI* were based on the CO_2 flux record. Net CO_2 fluxes over dairy pasture have previously been shown to respond strongly to grazing due to cycles of removal and regrowth of *LAI* (Campbell et al., 2015; Hunt et al., 2014). However, simulated *LAI* for the dairy pasture site explained only 6% of variability in daily ET_C. Net CO_2 flux similarly related poorly with ET_C at this site (R^2=0.02). Although *GPP* was more strongly correlated with ET_C (R^2=0.63), this is likely a reflection of the common dependence of evaporation and photosynthesis on solar radiation. Variation in *LAI* and CO_2 flux explained a greater proportion of variability in ET_C for the seed crop site, 38 and 35% respectively. The significance of this relationship may have resulted from the concurrence of seasonal increases in *LAI*, temperature, and solar radiation. These results, combined with the similarity of pasture and crop ET_C through repeated grazing cycles (Fig. 3) suggest that ET_C is relatively insensitive to changes in *LAI*, as has been shown at other well-watered grassland sites (Pronger et al., 2016; Stewart and Verma, 1992).

3.2 Comparison with reference evapotranspiration

Comparison of ET_C across measurement sites is likely to integrate the effects of environmental heterogeneity. Therefore, ET_C was compared with ET_0 calculated by the FAO-56 Penman-Monteith method in order to determine the relationship of ET_C to atmospheric demand in the contrasting management systems. There was close agreement between ET_C and ET_0 at the dairy pasture site where ET_C was 97% of ET_0 on average (Fig. 6). Estimated *LAI* and net CO_2 flux provided little explanatory value for variation in ET_C/ET_0 (R^2 = 0.07 and 0.02 respectively), supporting the argument that grazing cycles have little impact on ET_C.

For non-harvest periods, predictions of ET_C by ET_0 were slightly more variable for the crop site (R^2=0.73 vs. 0.91) and ET_C was 93% of ET_0 on average. This may reflect differences in the soil water balance of the two sites. While atmospheric demand (as estimated by ET_0) was completely fulfilled by precipitation and irrigation at the pasture site, potential evapotranspiration deficit was 107 mm for the first year and 84 mm for the second at the crop site, reflecting the management practice of drying the crop before harvest and cessation of irrigation following the final harvest. As well, application of irrigation water in a large events could result in loss of irrigation to soil drainage and contribute to the more variable pattern of soil moisture observed for the crop site (Fig.1). A lysimeter study of agricultural grasslands within Canterbury, New Zealand found that 18 – 33% of water applied as precipitation and irrigation may be lost to soil drainage (Duncan et al. 2015). Although in the present study, when a potential evapotranspiration deficit was present, ET_C was typically well matched with the amount of water applied as precipitation and irrigation (ET_C was 101% of applied water over the first season and 91% over the second at the crop site), leaving little margin for drainage. Tipping bucket rain gauges are known to underestimate low-intensity precipitation, such as fog and dew (Gebler et al., 2015), which may account for an underestimation of water availability for ET_C and drainage. While the single soil moisture measurement at each site is insufficient to assess soil water balance and drainage, and soil moisture only explained 2% of variability in ET_C, high temporal variability of the soil moisture, the apparent potential evapotranspiration deficit, and the larger difference with ET_0 all suggest a degree of water limitation to ET_C at the seed crop site.

Following the final harvest of the crop site in February 2013, ET_C was reduced to 35% of ET_0 (fig. 3, 6). Over this period, irrigation was discontinued, herbicide was applied to the crop and soil volumetric water content dropped to 10 m^3 m^{-3}. The combination of reduced water availability, as well as the reduction in transpiration due to crop removal likely caused the reduction in ET_C relative to ET_0.

3.2 Water-use efficiency

An important determinant of agricultural water-use efficiency is the partitioning of ET_C amongst its primary components, soil evaporation (E_S) and transpiration (Kool et al., 2014). Maximizing the proportion of transpiration is desirable, as this water is directly used for plant production. Soil evaporation, estimated from energy reaching the soil surface, was 50% greater for the pasture compared to the crop site (Fig. 3b). This increase is due to more frequent grazing cycles reducing leaf area and allowing more energy to reach the soil surface. In addition, while grazing cycles occurred throughout the year, mowing and harvest of the ryegrass crop typically occurred during shoulder seasons, when ET_0 was lower. The proportional contribution of E_S to ET_C over the first measurement period was 31% of ET_C for the pasture and 18% for the crop (Table 1). During the second season, E_S was 27% of ET_C at both sites, owing to the extended period of low *LAI* following final seed crop harvest. These values are based on assumptions of maximum and minimum *LAI* and represent only a likely scenario of how source components of ET_C vary between the two management systems. However, our estimates compare well with previous assessments of the contribution of E_S to ET_C for managed grassland systems using isotopic and modelling approaches, which ranged from 12-30% (Sutanto et al.; Zhang et al 2011).

Gross primary production (*GPP*) estimated from partitioned CO_2 fluxes over the course of the study was 4982 and 4637 g C m^{-2} for the pasture and crop site respectively. The annual rates of 2827 and 2628 g C m^{-2} for the first year exceed previous estimates of *GPP* for dairy pasture in New Zealand, which ranged from 1984-2404 g C m^{-2} (Mudge et al. 2011). However, this site was unirrigated and was impacted by a drought year. Ecosystem water-use efficiency, as determined by the ratio of carbon uptake as gross primary production (*GPP*) to water used for ET_C, indicate the pasture produced 3.09 g C m^{-2} mm^{-1} while the crop site was marginally greater, 3.25 g C m^{-2} mm^{-1}. However, when considering only crop water use efficiency, this trend was reversed, producing 4.39 and 4.18 g C m^{-2} mm^{-1} at the pasture and seed crop sites respectively.

4. Conclusions

While many studies have compared ET_C across contrasting cover types and irrigation regimes (Burba and Verma, 2005; Suyker and Verma, 2009), we have focused on the effects of management technique (grazing vs. harvest) for two irrigated grasslands with similar crop species. Despite different management practices, ET_C for irrigated dairy pasture and a ryegrass crop grown for seed were very similar, both to each other and their respective ET_0 predictions during periods of active crop growth. During this period, both land-uses evaporated at near-potential rates, indicating energy as the primary limitation to ET_C. Partitioning amongst transpiration and soil evaporation was different, with the pasture losing more water to soil evaporation (29% of *ET* as compared to 22% in the crop).

Despite this difference, water-use efficiency was similar for the two sites due to higher productivity of the pasture.

These results suggest that FAO-56 ET_0 provides an effective tool for effective management of irrigated perennial grass cover in New Zealand. Although, there was substantial variability surrounding the ET_C/ET_0 relationship at both sites, this difference should be viewed in light of potential uncertainties in the eddy covariance method (Scott, 2010) and uncertainty related to soil water balance. The largest differences in ET_C between sites and methods (ET_C vs. ET_0) observed during the study occurred following harvest of the ryegrass crop. This suggests that irrigation scheduling tools and hydrological modelling efforts should which rely on prediction of ET_C using ET_0 or similar methods should consider harvest practices, though not necessarily grazing schedules. The observed differences in ET_C between the two management systems could also serve to inform optimal land-use allocation in water limited irrigation schemes. In the Canterbury region, hydrologic drought is typically most intense in late-Summer (March) (Srinivasan and Duncan, 2011). As the crop was harvested in February and ET_C was reduced to 35% of ET_0, greater allocation of land to seed or silage crops in water-limited irrigation schemes would constitute water savings over the portion of the year when water limitation is greatest. However, depending on the length of the fallow season, these savings would come at the expense of grass production.

Acknowledgements

We are grateful to Craige Mackenzie and Eric Watson for use of their farms. Mark Crump and Jan Diettrich provided assistance with maintenance of eddy covariance instruments and data. We thank Dennis Finn and John Hunt for comments on the draft manuscript. This study was funded by the New Zealand Ministry of Business, Innovation and Employment (contract #C01X1006 Waterscape). John Kochendorfer was supported, in part, by a NIWA Visiting Scientist Award.

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Table 1: Total precipitation (*P*, mm), irrigation (*I*, mm), actual evapotranspiration (ET_C, mm), FAO-56 reference evapotranspiration (ET_0, mm) estimated from Equation (1), soil evaporation (E_S, mm) estimated from Equation (2) and gross primary production (*GPP*, g C $m^{-2}d^{-1}$) for the two measurement years (11 June2011- 10 June 2012 and 11 June 2012 – 4 March 2013) at the dairy pasture and ryegrass seed crop sites.

	Year 1		Year 2*	
	Pasture	Crop	Pasture	Crop
P	843	604	666	527
I	173	218	137	128
ET_C	791	829	819	598
ET_0	945	929	805	739
E_S	252	153	225	166
GPP	2827	2628	2155	2009

*incomplete year

Figure 1: Daily precipitation (P), irrigation (I) and soil volumetric water content (θ) for the pasture (A) and crop (B) study sites.

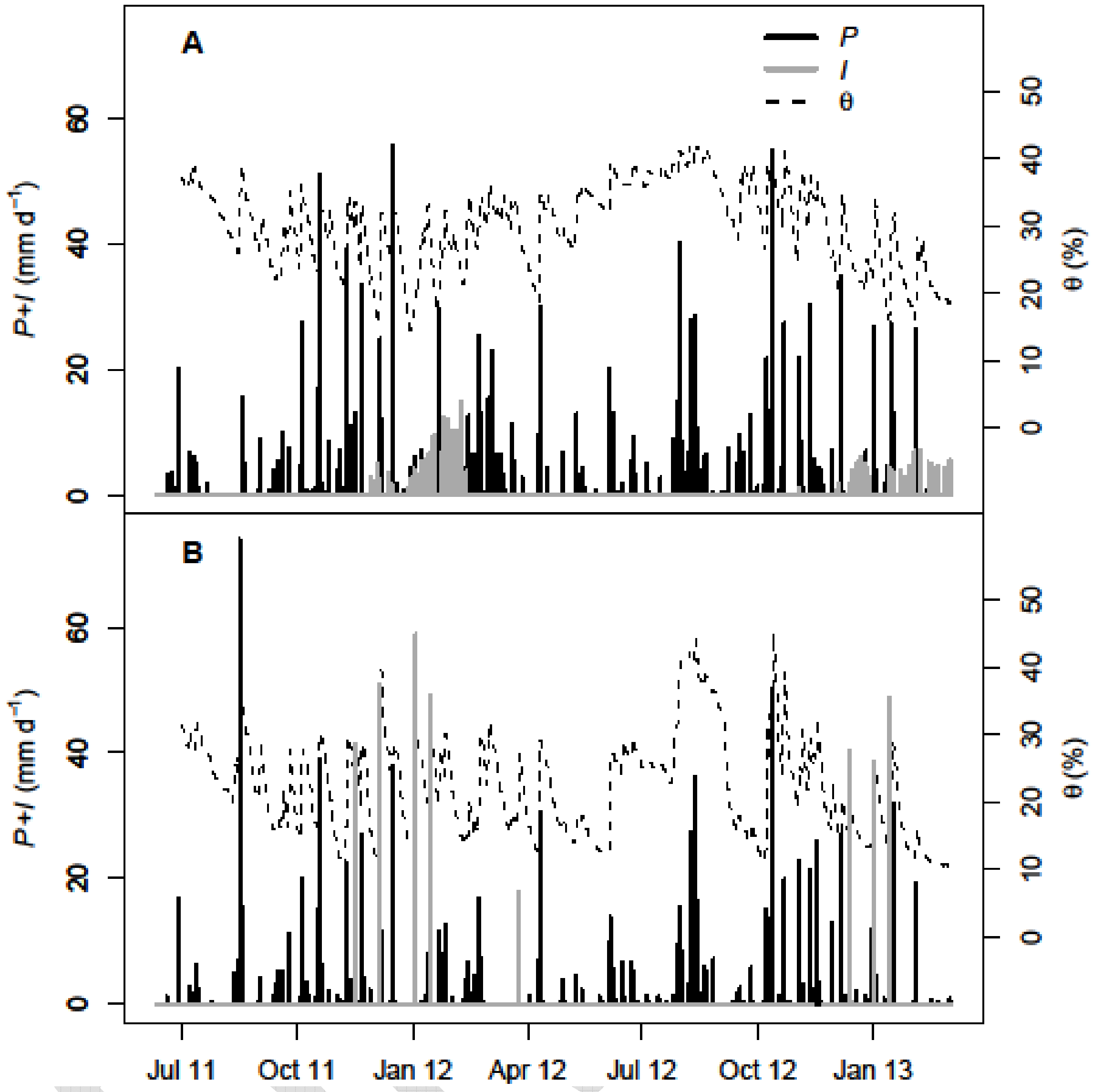
Figure 2: Seasonal leaf area index, *LAI*, estimated from Equation (3) for the pasture and crop sites.

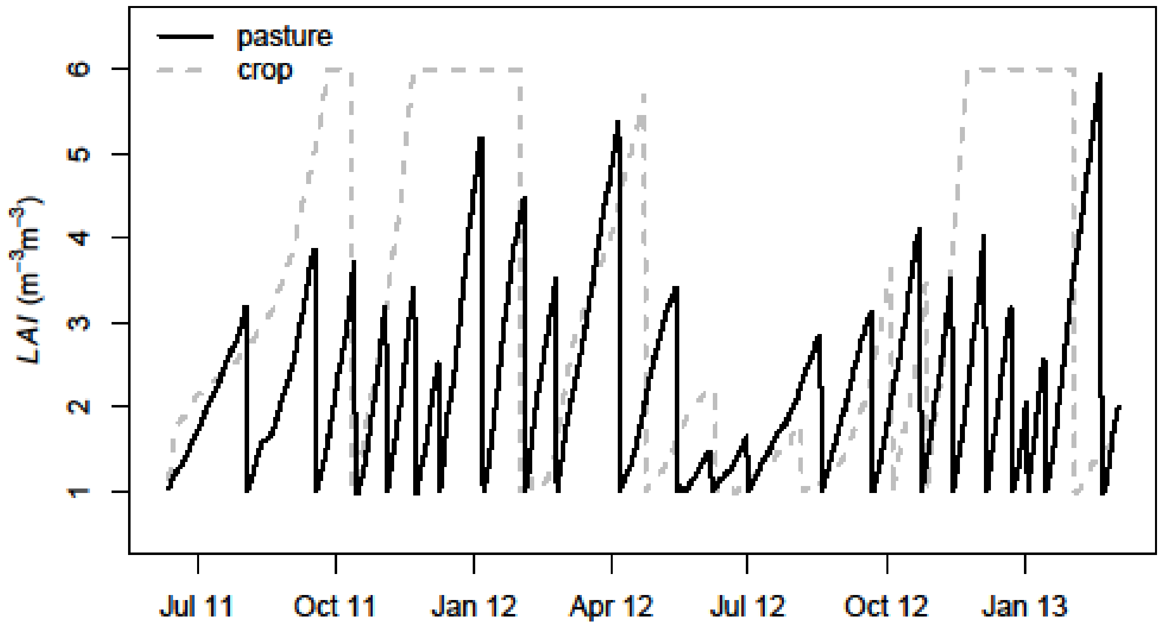
Figure 3: Daily (A) measured actual evapotranspiration, ET_C, (B) modelled soil evaporation, E_S, and (C) cumulative evapotranspiration, ΣET, for the pasture and crop sites over the entire measurement period 10 June, 2011 – 4 March, 2013; arrows indicate timing of pasture grazing events (black) and crop harvest/mowing events (grey).

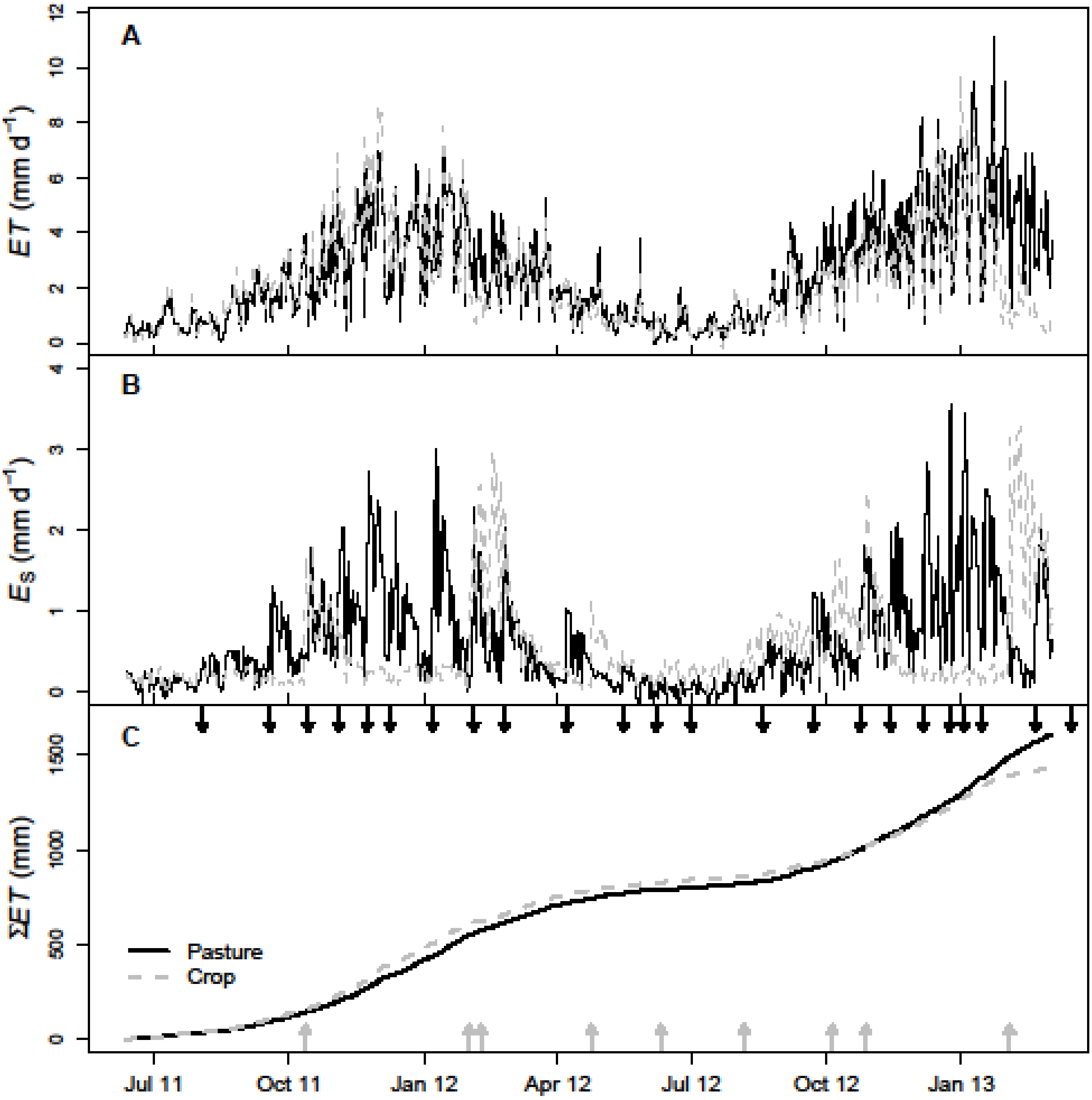
Figure 4: Mean diurnal course of (A) evapotranspiration, ET_C, and (B) vapour pressure deficit, D, for the pasture and crop eddy covariance sites during the first growing season (1 December, 2011 – 31 January, 2012).

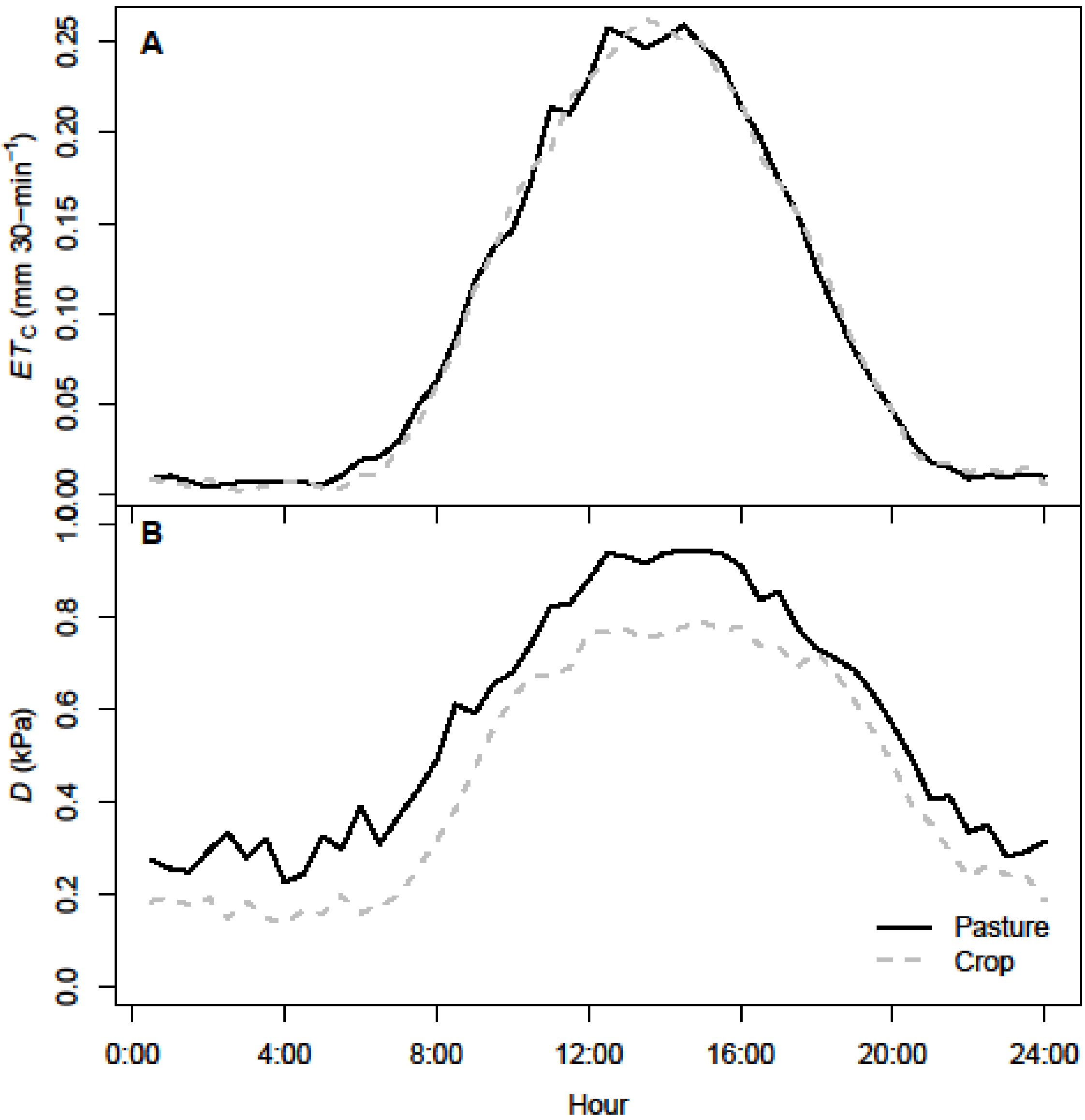
Figure 5: Half-hourly actual evapotranspiration, ET_C, for daylight hours (R_G>20 W m^{-2}) in response to (A) global radiation, R_G, (B) air temperature, T_{air}, and (C) vapour pressure deficit, D, during the first (1 December, 2011 – 31 January, 2012, left pane) and second (1 December, 2012 – 31 January, 2013, right pane) growing seasons; lines represent bin-averaged ET_C for the two sites.

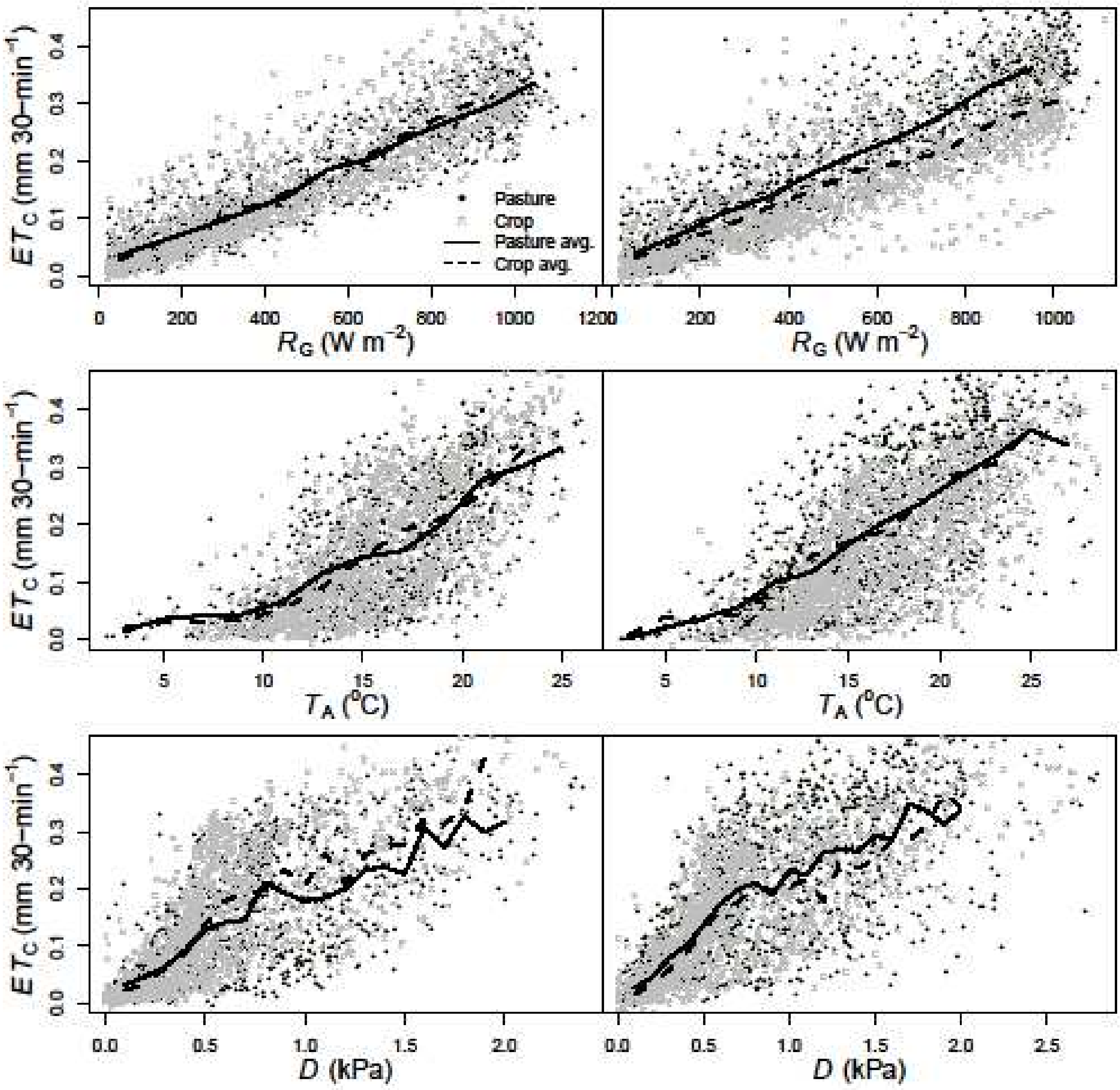
Figure 6: Daily actual evapotranspiration (ET_C) vs. reference evapotranspiration (ET_0) calculated from the FAO-56 Penman-Monteith method for (A) crop and (B) pasture sites; regression lines represent the slope of the ET_C/ ET_0 relationship with pre- and post-harvest periods indicated for the crop farm (final harvest only).


A
B
P
I
θ
P+I (mm d^{-1})
θ (%)
0
20
40
60
0
10
20
30
40
50
Jul 11
Oct 11
Jan 12
Apr 12
Jul 12
Oct 12
Jan 13

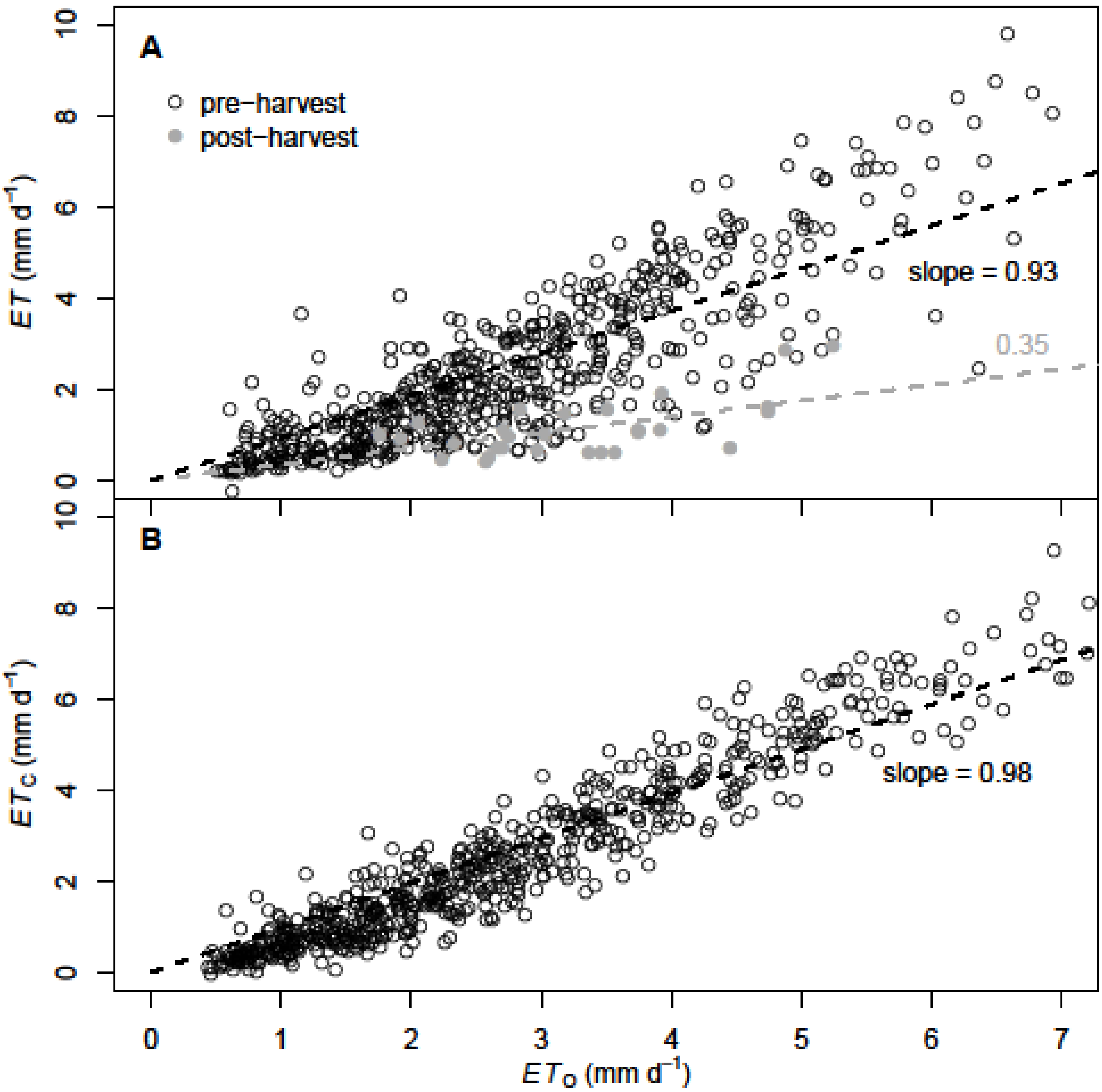

pasture
crop
LAI (m-3m-3)
1
2
3
4
5
6
Jul 11
Oct 11
Jan 12
Apr 12
Jul 12
Oct 12
Jan 13


A
B
C
ET (mm d-1)
Es (mm d-1)
ΣET (mm)
Pasture
Crop
Jul 11
Oct 11
Jan 12
Apr 12
Jul 12
Oct 12
Jan 13


A
B
ETC (mm 30−min−1)
0.00
0.05
0.10
0.15
0.20
0.25
D (kPa)
0.0
0.2
0.4
0.6
0.8
1.0
Pasture
Crop
0:00
4:00
8:00
12:00
16:00
20:00
24:00
Hour



ETC (mm 30–min-1)
RG (W m-2)
TA (0C)
D (kPa)
Pasture
Crop
Pasture avg.
Crop avg.


A
pre−harvest
post−harvest
slope = 0.93
0.35
B
slope = 0.98
ET (mm d^{-1})
ET_C (mm d^{-1})
ET_O (mm d^{-1})

546
547