

1 **Title:** Global synthesis of vegetation control on evapotranspiration partitioning

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3 **Running title:** Vegetation and *ET* partitioning

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Abstract

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Evapotranspiration (ET) is an important component of the global hydrological cycle. However, to what extent transpiration ratios (T/ET) are controlled by vegetation and the mechanisms of global-scale T/ET variations are not clear. We synthesized all the published papers that measured at least two of the three components (E , T , and ET) and leaf area index (LAI) simultaneously. Non-linear relationships between T/ET and LAI were identified for both the overall dataset and agricultural or natural data subsets. Large variations in T/ET occurred across all LAI ranges with wider variability at lower LAI . For a given LAI , higher T/ET was observed during later vegetation growing stage within a season. We developed a function relating T/ET to the growing stage relative to the timing of peak LAI . LAI and growing stage collectively explained 43% of the variations in the global T/ET dataset, providing a new way to interpret and model global T/ET variability.

36 1. Introduction

37 Evapotranspiration (ET) is an important component of hydrological cycles and may
38 account for greater than 95% of all precipitation inputs in water-limited ecosystems
39 [Wilcox and Thurow, 2006]. Evapotranspiration represents a central linkage between
40 water and energy flux across various ecosystems [Katul *et al.*, 2012; Wang and
41 Dickinson, 2012]. Evapotranspiration comprises two components: evaporation (E) and
42 transpiration (T). Separating ET components and assessing the factors controlling the
43 partitioning not only improve our knowledge of water budget but also enhance our
44 understanding of plant water use mechanism and efficiency, which will reduce
45 uncertainties in the interpretation of the coupling of water and carbon/nutrient cycles
46 [Austin *et al.*, 2004]. The T/ET ratio has been reported to be 80-90% at the global scale
47 (up to 95% in desert catchments) based on isotopic analyses in lake systems [Jasechko *et*
48 *al.*, 2013]. The modeling assumption of that study is subject to debate [e.g., Schlaepfer *et*
49 *al.*, 2014] and a larger T/ET range is reported in a more recent study [Coenders-Gerrits *et*
50 *al.*, 2014], which emphasizes the need for more comprehensive evaluations of the global
51 T/ET variations.

52 Because of the importance of separating E and T , there are many studies focusing
53 on ET partitioning in both agricultural setting [e.g., Harrold *et al.*, 1959; Sakuratani,
54 1987; Yunusa *et al.*, 2004] and natural systems [e.g., Sammis and Gay, 1979; Kelliher *et*
55 *al.*, 1992; Oren *et al.*, 1998; Wilson *et al.*, 2000; Wang *et al.*, 2013] from plot to
56 ecosystem scale. Some recent works have aimed at developing new tools capable of
57 partitioning ET components at the landscape scale [Scanlon and Kustas, 2010; Wang *et*
58 *al.*, 2010; Good *et al.*, 2012]. Transpiration is directly related to vegetation activity,

59 therefore it is not surprising that vegetation has a strong control on ET partitioning [e.g.,
60 *Good et al.*, 2014; *Schlesinger and Jasechko*, 2014], though factors affecting E also
61 influence T/ET . Wang et al. [2010] provided experimental evidence of ET partitioning
62 changes along with vegetation cover change, and they found that T/ET increased from
63 60% at 25% cover to 83% at 100% cover. However, it is still not clear to what extent that
64 T/ET ratios are controlled by vegetation and what are the additional factors that could
65 further explain the T/ET variations at a global scale. This hinders our predictions of future
66 hydrological changes since vegetation provides a strong feedback to water cycling. To
67 better answer these questions, we synthesized all the available literature data with
68 simultaneous ET partitioning data and leaf area index (LAI). The objective of this study is
69 to establish a quantitative relationship between ET partitioning and vegetation cover
70 index (e.g., LAI) for different systems (i.e., agricultural vs. natural systems), and to
71 explain the variations of observed T/ET at the global scale.

72 **2. Materials and Methods**

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74 **2.1 Data collection**

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76 We conducted article searches in ISI Web of Science and Google Scholar, and retrieved
77 the references cited in papers. The following criteria were used to include papers in our
78 synthesis: 1) at least two out of the three parameters (E , T and ET) were independently
79 and experimentally measured; and 2) leaf area index was quantified simultaneously with
80 E , T and ET measurements. As a result, 48 individual publications before May 31 2014
81 were included in our analysis (Auxiliary Material_text01). There were multiple LAI and
82 T/ET information for some studies, which tracked the vegetation development. Therefore
83 the 48 studies resulted in 334 sets of data. We extracted E , T , ET and LAI values directly

84 from tables or text in original papers, or indirectly from figures using GraphClick
85 software (Arizona software, USA). The units of E , T or ET were unified into mm d^{-1} , the
86 unit conversion is important when using ET to explain the T/ET variations. Ancillary
87 information including latitude, longitude, soil water potential, mean annual rainfall,
88 ecosystem types were also recorded whenever they were available. We calculated stress
89 level based on available soil water potential and vapor pressure deficit (VPD) information
90 of each study. When the VPD information was not available from the individual study, it
91 was extracted from a global forcing dataset [Sheffield *et al.*, 2006] based on the latitude
92 and longitude of the study site.

93 **2.2 Data analyses**

94
95 The relationships between LAI and T/ET were analyzed using quantile regression [Cade
96 and Noon, 2003] for agricultural settings, natural settings and the overall dataset.
97 Quantile regression estimates multiple change rates from minimum to maximum
98 responses, providing a more complete picture of the relationships between variables
99 missed by other regression methods. In this study, 95% fitting [Cade and Noon, 2003]
100 was established to capture the maximum constraints of LAI on T/ET for various systems.
101 The data analyses were conducted using Matlab 8.2 (MathWorks, Natick, MA, USA).

102 **3. Results and Discussion**

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104 Separating ET components, assessing the controlling factors of ET partitioning and
105 predicting ET partitioning change under different climate regimes are important for
106 estimating water budgets, predicting ecosystem dynamics and predicting hydrological
107 responses to future climatic changes [Newman *et al.*, 2010; Cavanaugh *et al.*, 2011;
108 Wang *et al.*, 2012; Jasechko *et al.*, 2013; Wang *et al.*, 2013]. Based on our synthesis, the

109 majority of the *ET* partitioning studies focused on agricultural settings (29 out of 48
110 studies) and the number of studies focusing on natural setting was increasing in recent
111 years (Auxiliary Material_text01). The studies with simultaneous measurements of *ET*
112 partitioning and *LAI* appeared in most of the continents though the majority of the studies
113 were conducted in US (Auxiliary Material_fs01). Based on isotopic analyses in lake
114 systems, the *T/ET* ratio has been reported to be 80-90% at the global scale [*Jasechko et*
115 *al.*, 2013]. A later study argues that such results are biased due to unrepresentative input
116 data in the modeling and that another choice of input data could result in *T/ET* of 35-80%
117 [*Coenders-Gerrits et al.*, 2014]. The current synthesis based on all the available data from
118 global scale field measurements showed a range of 38-77% (Figure 1), supporting the
119 number reported in Coenders-Gerrits et al. [2014].

120 The quantile regression showed that there were non-linear relationships between
121 *LAI* and *T/ET* for both agricultural and natural systems, and for the overall dataset. The
122 95% quantile regression line reflects the practical upper limit of vegetation control on
123 *T/ET* under a certain *LAI* (Figure 2a-c). The best fits between *LAI* (*x*) and *T/ET* (*y*) are *y*
124 = 0.91*x*^{0.07} for agricultural systems, *y* = 0.77*x*^{0.10} for natural systems, and *y* = 0.91*x*^{0.08} for
125 the overall dataset (Figure 2a-c). The results showed that even under low *LAI* conditions
126 (e.g., *LAI* = 0.5), *T/ET* value could be up to 0.72 and 0.90 for natural and agricultural
127 systems, respectively (Figure 2a-c). The agricultural systems tend to have higher
128 transpiration proportion under the same *LAI* value, which is likely due to the fact that
129 agricultural plants are typically less constrained by environmental stress. The exponential
130 relationship between *LAI* and *T/ET* indicates that large change in vegetation control on
131 *T/ET* occurs over the lower *LAI* range, showing the possibility of high proportion of

132 vegetation water use even under low *LAI* conditions.

133 There were large variations in *T/ET* over the entire range of *LAI* values. We used
134 stress levels (both soil water potential and vapor pressure deficit) and *ET* levels to
135 separate *T/ET* responses across the *LAI* range, but it did not help explain the variability in
136 *LAI* (i.e., *T/ET* variability did not correspond to either different *ET* levels or stress levels,
137 data not shown). Inconsistent methodology in quantifying *T/ET* across the different
138 studies and inherent variations in plant water use characteristics may contribute to the
139 variability. However, we hypothesize that vegetation growing stage may play a more
140 important role since different levels of physiological activities (e.g., photosynthesis) are
141 often seen under different growing stages [Vries, 1989]. To test this hypothesis regarding
142 variations in *T/ET*, we developed a plant growing stage function (*S*),

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144
$$S = \sin\left(\frac{\pi}{2} \frac{DOY - DOY_{LAI_{max}}}{365}\right)$$

145 where *DOY* refers to day of year; and *LAI_{max}* is the maximum *LAI* observed during the
146 experiment. Basically *S* is a time function relating the time of measurement to the timing
147 of peak *LAI*. A value of *S* = 0 refers to the peak *LAI* stage, while *S* = -1 is the beginning
148 of the growing season and *S* = +1 is the end of the growing season.

149 By incorporating *LAI* and *S*, *T/ET* can be modeled by the following functions,

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$$T/ET = 1 - e^{c_1 LAI + c_2 S + c_3}$$

151 where *c*₁, *c*₂ and *c*₃ are constants; and *S* is the growing stage function. These two
152 parameters (*LAI* and *S*) collectively explained 43% of the variations in the global *T/ET*
153 dataset (Figure 2d). The results showed that under the same *LAI* condition, the *T/ET* was
154 affected by the growing stage. The *T/ET* was lower for the early stage and higher for the

155 late stage during one growing season under the same *LAI* condition (Figure 2d). This is
156 likely due to reduced evaporation under higher litter cover or crop residue after the peak
157 *LAI* stage, similar to what is found in Wang et al. [2013] in a temperate grassland
158 ecosystem. With the availability of frequent, global estimates of *LAI* and *ET*, it is feasible
159 to use the *LAI* and *S* information to generate a global scale *T/ET* dataset. Continuous
160 estimates of *T/ET* will significantly enhance our understanding of global vegetation water
161 use and dynamics of water vapor isotopes and would be very useful to validate various
162 global hydrological models.

163 This study presents a comprehensive global dataset of vegetation leaf area and *T/ET*,
164 providing a guidance and reference for future *ET* partitioning studies. The 95% quantile
165 regression line indicates the practical upper limit of vegetation control on *T/ET* under a
166 fixed *LAI* value. More importantly, the study indicates that if we incorporate information
167 of *LAI* and vegetation growing stage, almost half of the variability in *T/ET* could be
168 explained, providing a new way to interpret and model the global *ET* partitioning
169 variability.

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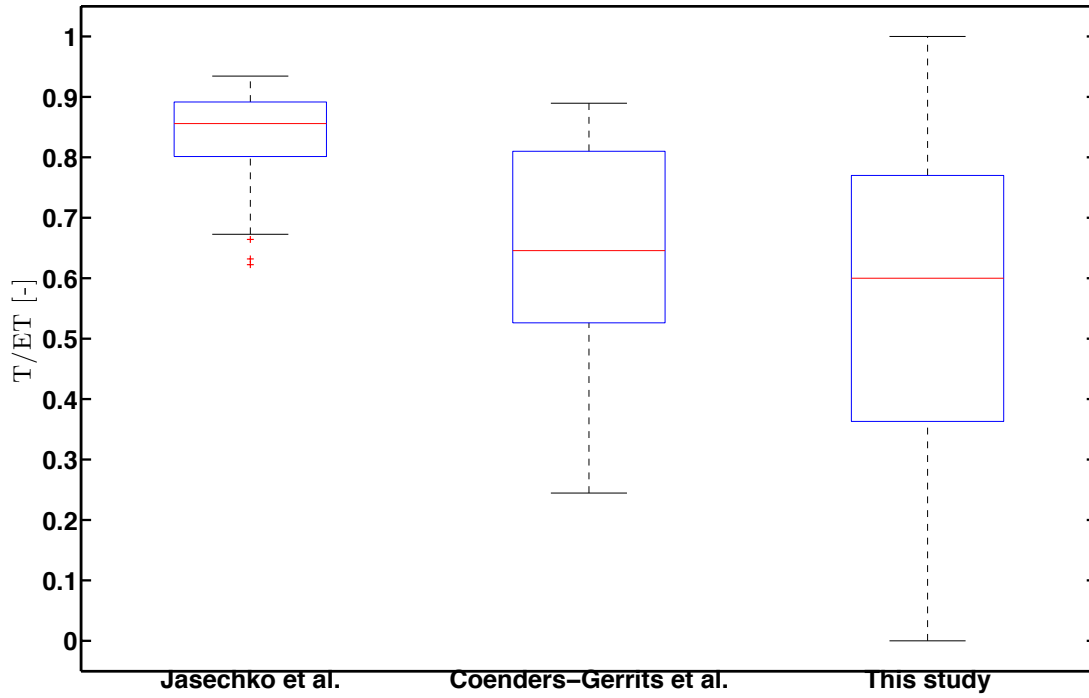
247 **Figure legends**

248 Figure 1. Ratio of transpiration to evapotranspiration (T/ET) at a global scale. Box plots
249 are from Coenders-Gerrits et al. 2014 (A-B) and of the current study (C). The blue box
250 indicates the 25th and 75th percentiles with the median in red. The error bars indicate the
251 minimum and maximum values. The red crosses indicate outliers.

252

253 Figure 2. The relationship between the ratios of transpiration to evapotranspiration (T/ET)
254 and leaf area index (LAI) for the overall dataset (A), agricultural systems, and (B) natural
255 systems (C). The dashed lines depict the 95% quantile regression line. (D) The
256 relationship between T/ET and LAI , plant growing stage function (S). The variability in
257 T/ET and LAI relationship was partially explained by S .

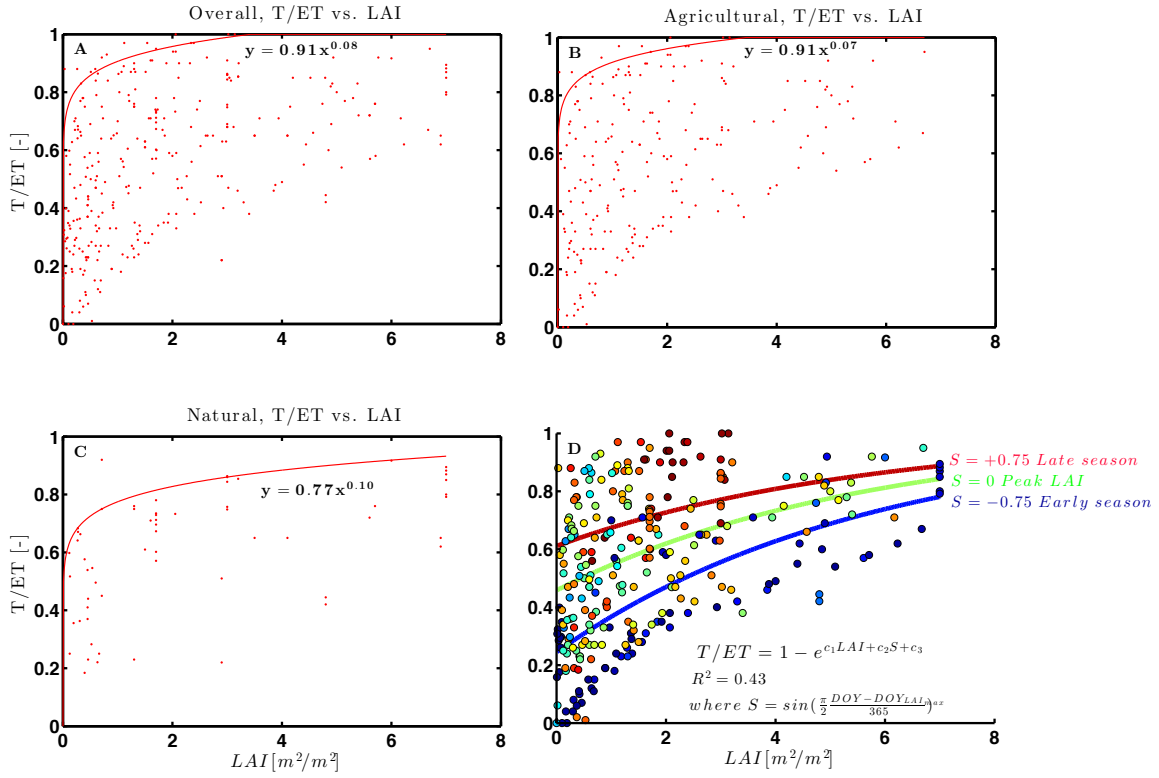
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261 Figure 1.



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264 Figure 2

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