

1 **Energy partitioning and evapotranspiration over a black locust**
2 **plantation in the Yellow River Delta**

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35

36 **Abstract**

37

38 Woody plantations play a curtail role in ecological security along coastal zones.
39 Understanding of energy partitioning and evapotranspiration (ET) over black locust
40 plantations can reveal land-atmosphere interaction process and help us to optimize
41 this plantation for land management in the Yellow River Delta. In this study, we
42 investigated energy fluxes, ET in particular, and their related biophysical factors using
43 eddy covariance techniques over a black locust plantation in 2016, 2018, and 2019.
44 Downward longwave radiation offsets 84%–85% of upward longwave radiation,
45 upward shortwave radiation accounted for 12%–13% of downward shortwave
46 radiation, and the ratio of net radiation (R_n) to downward radiation was 18%–19% in
47 the three years. During growing seasons, latent heat flux was the largest components
48 among radiation balance terms; during non-growing seasons, sensible heat flux was a
49 dominant component. ET was mainly controlled by R_n , air temperature, vapor
50 pressure deficit and leaf area index (LAI). Annual ET was smaller than the sum of
51 precipitation and irrigation, and cumulative ET was larger than cumulative
52 precipitation during non-growing seasons. The phenology of black locust influenced
53 the seasonal variation in daily ET, mainly via LAI. ET was larger under sea wind than
54 under land wind, mainly because soil water content at 10-cm depth was greater under
55 sea wind in daytime. Seasonal patterns of daily evaporative fraction, Bowen ratio,
56 crop coefficient, Priestley–Taylor coefficient, surface conductance (g_s), and
57 decoupling coefficient were mainly controlled by LAI, and the threshold value of
58 daily g_s was approximately 8 mm s^{-1} over the studied plantation.

59

60 **Keywords:** Black locust plantation, Yellow River Delta, Eddy covariance, Energy
61 partitioning, Evapotranspiration

62

63 **1. Introduction**

64

65 The precise quantification of energy exchange between the land surface and the
66 atmosphere is required by the field of numerical weather predictions and climate
67 modeling, since the land surface thermodynamic and hydrological processes are
68 closely coupled to the atmospheric circulation process (Valayamkunnath et al., 2018;
69 Ward et al., 2014; Odongo et al., 2016). The studies on surface radiation balance and

70 energy partitioning are promoted by the development of global climate change
71 sciences (Chen et al., 2016). The partitioning of net radiation (R_n) into sensible heat
72 flux (H), latent heat flux (LE), soil heat flux (G), and heat storage in the vegetation
73 plays a critical role in the turbulence flow structure and thermodynamic process of the
74 boundary layer, and hence directly influences the Earth's climate system at local,
75 regional, and ultimately global scales (You et al., 2017; Odongo et al., 2016; Chen et
76 al., 2016). On the other hand, the changes in land cover and climate in turn affect a
77 variety of physical and physiological processes in the vegetation and finally alter the
78 energy exchange between the land surface and the atmosphere (Zhu et al., 2014).
79 Previous studies have demonstrated that the surface albedo is often lower in forests
80 than cropland, grassland, and deserts, and so forests could use more solar radiation
81 (Gao et al., 2018; Yue et al., 2019; Zhu et al., 2014). The forests cover approximately
82 30% of the total land surface of the Earth (Iida et al., 2006) and distribute from the
83 tropical to frigid zones. Their energy partitioning varies with forest types (Liu et al.,
84 2018; Betts, 2000). Therefore, a better understanding of the energy partitioning in
85 different forest types under various environmental conditions is required to describe
86 complex interactions between the terrestrial biosphere and atmosphere as well as
87 water circulation and global climate change (Zhu et al., 2014).

88 Evapotranspiration (ET, i.e. LE in an energy unit) is the amount of water into the
89 atmosphere from the land surfaces. ET is the sum of evaporation from bare soil and
90 wet vegetation canopy surface and transpiration out of plant stomas (Valayamkunnath
91 et al., 2018; Iida et al., 2020). The ET consumes about 60% of annual precipitation
92 globally on the land surface (Jung et al., 2010; Odongo et al., 2016), and is the link
93 between hydrological cycle and energy exchange processes. Leaf stomata controls
94 vegetation transpiration and photosynthesis. Therefore, ET is closely coupled to
95 carbon uptake at an ecosystem scale (Aires et al., 2008; Jia et al., 2016). The
96 variations of ET are generally controlled by meteorological factors, vegetation
97 properties and soil water conditions (Gao et al., 2018; Yue et al., 2019;
98 Valayamkunnath et al., 2018). In recent years, reforestation rates have been rapidly
99 increasing in China, and so far forest plantations, critical for ecological protection,
100 account for about 33% of forestland in China (Chen et al., 2014; Ma et al., 2019),
101 which has dramatically shown the role of vegetation in the afforested/reforested areas.
102 Therefore, it is motivated to investigate the ET process related to its control factors
103 determining the mechanisms by which hydrological cycle and energy exchange are

104 regulated for carbon sequestration and other ecosystem processes in plantations.

105 The Yellow River Delta on the north coastline of China covers an area of about
106 5.4×10^3 km², provides the habitats on the East Asian-Australasian Flyway (Liu et al.,
107 2020), has a population over two millions, and supports the largest petroleum industry
108 in China (Zhou et al., 2015). The delta, significantly affected by land-ocean
109 interaction (Kong et al., 2015), is a typical ecologically vulnerable area with low
110 water table (average depth is 1.14 m) and vast saline-alkali soil area (2.4×10^3 km²) (Li
111 et al., 2019). Attributed by human intervention and climate change, the delta
112 undergoes intensive conversion from natural wetland to croplands and plantations
113 (Chi et al., 2018). Studies have shown that plantations decrease water table through a
114 large amount of transpiration and control soil saltation through restraining the direct
115 movement of soil water from deeper layers to the soil surface that leaves its salt on the
116 surface and evaporates itself into atmosphere, and finally improving ecological
117 environment and promoting region sustainable development (Minhas et al., 2020).
118 The plantations play a key role in maintaining ecological security. This role needs
119 better understanding through the investigation of land surface processes as impacted
120 by this pivotal ecosystem in the Yellow River Delta. Revealing the maintenance and
121 control mechanisms of the energy partitioning and ET over the plantations in the
122 Yellow River Delta could improve our understanding of land-atmosphere interaction
123 process and provide support for plantation management in the coastal zone
124 of northern China.

125 Black locust (*Robinia pseudoacacia*) is a nectar source and fast-growing timber tree
126 species native to North America (Jiao et al., 2019). More importantly, this species is
127 one of the most ecologically friend species due to its function role in effective erosion
128 reduction, soil improvement and carbon sequestration, and now it is widely used in
129 ecological projects in the northern China (Jiao et al., 2018). As black locust can be
130 grown on the mild saline and alkaline soil (Ma et al., 2013), it is a major tree species
131 for afforestation to improve ecological environment in the saline-alkali land, and the
132 black locust plantations have covered 8000 hm² in the Yellow River Delta (Cao et al.,
133 2012). A number of studies have investigated water vapor flux and its control
134 mechanism over black locust plantations on the Loess Plateau, due to the complexity
135 in terrain landform only tree transpiration was measured using the sapflow technique,
136 and energy partitioning could not be analyzed in those studies (Jiao et al., 2018; Jiao
137 et al., 2019; Zhang et al., 2020). Given that the natural environment on the Loess

138 Plateau is entirely different from that in the coastal zone, it is vital to investigate water
139 vapor and energy fluxes and their dominant influences under global climate change in
140 the Yellow River Delta to fill up the gaps in the previous studies.

141 Over the past two decades, the eddy covariance (EC) technique has become a standard
142 method for measuring the exchange of water vapor and energy between the land
143 surface and atmosphere (Gao et al., 2017). In this study, we used 3-year energy and
144 water vapor fluxes observed by the EC technique and related biophysical data over a
145 black locust plantation in the Yellow River Delta. Our objectives are to: (1)
146 characterize energy fluxes and ET varied on diurnal and seasonal scales; (2) assess the
147 effects of environmental drivers on energy partitioning and ET; (3) determine the
148 surface parameters characterizing energy partitioning and evapotranspiration.

149

150 **2. Materials and methods**

151

152 *2.1. Study site*

153 Study site is located at Forest Ecosystem Research Station of the Yellow River Delta
154 in Shandong (37°54'2" N, 118°49'2" E, 3.4 m a.s.l.), Hekou district, Dongying city,
155 China (Fig.1). It is flat and experiences a warm-temperate continental monsoon
156 climate, with a mean annual air temperature of 12.3 °C and a mean annual frost-free
157 period of 210 days. The mean annual precipitation is 574.4 mm with approximately
158 70% occurring in summer, and the mean annual evaporation is 1962.1 mm (Zhang
159 and Xing, 2009). The soil in this site is a Fluvisol (FAO, 2000) and developed on
160 mixed loess and alluvium, and the volumetric water content of field capacity and
161 wilting humidity are 0.28 cm³ cm⁻³ and 0.10 cm³ cm⁻³, respectively, with bulk density
162 of 1.45 g cm⁻³. The soil is a mild saline-alkali soil, with salt content of 1.53 g kg⁻¹ and
163 pH value of 8.55. The black locust plantation is 35 years old, with stand density of
164 581 stems ha⁻¹, diameter at breast height of 18.6 cm, and canopy height of
165 approximately 14.5 m. The understory vegetation is mainly Bermuda grass (*Cynodon*
166 *dactylon*).

167 **(Fig.1)**

168 *2.2. Measurements*

169 A 25-m tall tower was constructed in the black locust plantation for mounting
170 turbulent fluxes and meteorological instruments. The details of those instruments are

171 shown in [Table 1](#). All sensors on the tower are connected to a CR1000 Datalogger
172 (Campbell Scientific Inc., Logan, UT, USA). The data from the measurements of
173 2016, 2018, and 2019 are used in this study.

174 The distance of the tower to nearest boundary of the plantation is approximately 450
175 m. The daily precipitation (P) and groundwater depth (GD) were acquired from
176 Yellow River Delta Ecological Research Station of Coastal Wetland, Chinese
177 Academy of Sciences and nearby national groundwater depth monitoring station
178 (<http://xxzx.mwr.gov.cn/>), respectively.

179 Based on previous study ([Yuan et al., 2014](#)), we divided growing season (GS) into
180 three phenological stages (early growing stage, EG; mid growing stage, MG; and later
181 growing stage, LG). The EG stood for the germination and leaf expansion period; the
182 MG included the vegetative phase, blooming, and fruit ripening stage; and the LG
183 was the leaf senescence period. The start date and end date of each phenological stage
184 is shown in [Table 2](#), and the rest of the year was the non-growing season (NG). The
185 plantation was irrigated once annually at the beginning of the GS.

186 According to downward shortwave radiation below/above the canopy (S_{db}/S_{da}), leaf
187 area index (LAI) was calculated by inverting the Beer's law equation:

$$188 S_{db} = S_{da} \exp(-\kappa LAI) \quad (1)$$

189 Where κ is the extinction coefficient of light attenuation (0.54, [Li et al., 2018](#)).

190 **Table 1**

191 *2.3. Data processing*

192 The post-processing of turbulent fluxes contains the necessary procedures for quality
193 control and correction. The quality control of turbulent fluxes data includes basic
194 tests, statistical tests, and tests on fulfillment of theoretical requirements ([Foken et al.,
195 2004](#)). And the correction of turbulent fluxes data includes the traditional coordination
196 rotation ([McMillen, 1988](#)), sonic temperature correction ([Schotanus et al., 1983](#)),
197 density fluctuations correction ([Webb et al., 1980](#)). For missing flux data due to
198 unacceptable low quality, instrument malfunction, and unfavorable weather
199 conditions, short gaps (≤ 2 h) were filled using a linear interpolation, and long gaps ($>$
200 2 h) were filled using the mean diurnal variation (MDV) method described by [Falge et
201 al. \(2001\)](#).

202 According to the measurements from net radiation sensor above the canopy, net
203 longwave/ shortwave radiation (L_n/S_n), and net radiation (R_n) were expressed as

204 follows:

$$205 \quad L_n = L_d - L_u \quad (2)$$

$$206 \quad S_n = S_d - S_u \quad (3)$$

$$207 \quad R_n = L_n - S_n \quad (4)$$

208 Where L_d/L_u and S_d/S_u represent downward/upward longwave radiation and
209 downward/upward shortwave radiation, respectively.

210 In this study, ET was expressed as follow:

$$211 \quad ET = \dot{c} / \lambda \quad (5)$$

212 Where λ denotes the latent heat of the vaporization of water (2.45 kJ g⁻¹, [Zhang et al.,](#)
213 [2016](#))

214 The Bowen ratio (β) and evaporative fraction (EF) were expressed as follows:

$$215 \quad \beta = H / \dot{c} \quad (6)$$

$$216 \quad EF = \dot{c} / R_n \quad (7)$$

217 The crop coefficient (K_c) was given by [Allen et al. \(1998\)](#) as follows:

$$218 \quad K_c = ET / ET_0 \quad (8)$$

$$219 \quad ET_0 = \frac{0.408 \Delta (R_n - G) + 900 \cdot U \cdot \gamma \cdot VPD / (T_a + 273.3)}{\Delta + \gamma (1 + 0.34 U)} \quad (9)$$

220 Where ET_0 is reference evapotranspiration, T_a signifies air temperature (°C), U
221 represents wind speed (m s⁻¹), VPD stands for the vapor pressure deficit (kPa), Δ is
222 the slope of the water vapor pressure curve (kPa °C⁻¹), and γ signifies the
223 psychrometric constant (kPa °C⁻¹).

224 The Priestley–Taylor coefficient (α) was given by [Priestley and Taylor \(1972\)](#) as
225 follows:

$$226 \quad \alpha = \dot{c} (\Delta + \gamma) / \Delta (R_n - G) \quad (10)$$

227 The aerodynamic conductance (g_a) and decoupling coefficient (Ω) were estimated
228 according to [Monteith and Unsworth \(1990\)](#), and surface conductance (g_s) was
229 calculated by inverting the Penman–Monteith equation ([Allen et al., 1998](#)):

$$230 \quad g_a = \left(\frac{U}{U_{\dot{c}}} + 6.2 U_{\dot{c}}^{-2/3} \right)^{-1} \quad (11)$$

$$231 \quad g_s = \frac{\gamma \cdot \leq \cdot g_a}{\Delta (R_n - G) + \rho_a \cdot c_p \cdot VPD \cdot g_a - \dot{c} (\Delta + \gamma)} \quad (12)$$

$$232 \quad \Omega = \frac{\Delta + \gamma}{\Delta + \gamma \dot{c} \dot{c}} \quad (13)$$

233 Where U_* is friction velocity (m s⁻¹), ρ_a is air density (1.2 kg m⁻³, [Gao et al., 2018](#)),

234 and c_p is the specific heat of dry air ($1004.7 \text{ J kg}^{-1} \text{ }^\circ\text{C}^{-1}$, Gao et al., 2018).

235

236 3. Results

237

238 3.1 Biophysical factors

239 Seasonal variations in biophysical factors in three study years are shown in Fig.2.

240 Daily average air temperature (T_a) ranged from $-12.5 \text{ }^\circ\text{C}$ in winter to $32.0 \text{ }^\circ\text{C}$ in
241 summer, and daily average air relative humidity (H_a) fluctuated around 60% (Fig.2a).

242 Daily average vapor pressure deficit (VPD) increased to the maximum value of > 2.0
243 kPa in early summer, and decreased to the minimum value of < 0.5 kPa in winter

244 (Fig.2b). Daily groundwater depth (GD) ranged from 1.4 m to 2.2 m between 12 June
245 2018 and 31 December 2019 (Fig.2b). Daily average wind speed (U) usually

246 fluctuated above 2.0 m s^{-1} , and the maximum value of U was 8.0 m s^{-1} in this 3-year
247 study (Fig.2c). Annual precipitation (P) was 662.00 mm, 489.30 mm, and 487.50 mm

248 chronologically for three study years. The amount of irrigation (I) water was 80 mm
249 in each year. Soil water content at 10 cm depth (SWC_{10}) closely depended on P and I

250 amounts, and the severe drought occurred in 2019 as soil water content at 40 cm
251 depth (SWC_{40}) was lower than $0.17 \text{ cm}^3 \text{ cm}^{-3}$ (the relative extractable water dropped

252 content was equal to 0.4, Ma et al., 2018) lasted 73 days (Fig.2d). The maximum
253 value of leaf area index (LAI) was $3.08 \text{ m}^2 \text{ m}^{-2}$, $3.14 \text{ m}^2 \text{ m}^{-2}$, and $2.20 \text{ m}^2 \text{ m}^{-2}$ in

254 chronologically for three study years. In the MG of 2018, the canopy of black locust
255 plantation was damaged by a hailstorm (14 August), which resulted in a noticeable

256 drop in LAI (Fig.2e).

257 (Fig.2)

258 Table 2

259 3.2 Energy partitioning

260 The seasonal variations in daily downward /upward longwave radiation (L_d/L_u) and
261 downward /upward shortwave radiation (S_d/S_u) displayed parabolic trends; the peak

262 value of daily L_d and L_u usually appeared in early August, and that of daily S_d and S_u
263 usually appeared in early June (Fig.3a). In cloudy days, the difference between daily

264 L_d and L_u and that between daily S_d and S_u were small, which resulted that daily net
265 longwave /shortwave radiation (L_n/S_n) were close to 0. The maximum value of daily

266 S_n usually appeared in early June, and daily L_n fluctuated between 0 to -102.7 W m^{-2}

267 (Fig.3b). The daily albedo increased sharply in winter due to snow cover on the
268 ground, and the general trend of daily albedo had an apparent peak value in the EG
269 (Fig.3c).

270 (Fig.3)

271 According to 30-min data, the energy balance closure was stable at our station in this
272 study. The annual energy balance ratios were 0.68–0.69 with the slopes of 0.57, the
273 goodness-of-fit (R^2) values of 0.85–0.86, and the intercepts between 12.05 W m^{-2} and
274 12.50 W m^{-2} (Table 3).

275 Table 3

276 The seasonal course of daily net radiation (R_n) is a parabolic curve, ranging from –
277 18.5 W m^{-2} in winter to 265.4 W m^{-2} in summer (Fig.4a). There was one peak in the
278 seasonal course of daily sensible heat flux (H), appearing at the mid-April (Fig.4b).
279 Daily latent heat flux (LE) was usually smaller than 10.0 W m^{-2} in winter, and greater
280 than 120.0 W m^{-2} after rainy days in summer (Fig.4c). Daily soil heat flux (G) ranged
281 from -19.7 W m^{-2} to 13.7 W m^{-2} , and was usually below 0 in autumn and winter and
282 above 0 in spring and summer (Fig.4d). Diurnal cycle of the monthly average R_n and
283 its components for three study years are shown in Fig.5. The diurnal cycle of monthly
284 average R_n and H showed clear diurnal variations, and peaked at noon. The largest
285 diurnal peaks of R_n and H were 690.76 (May 2019) and 332.21 (April 2016) W m^{-2} ,
286 respectively. The diurnal cycle of monthly average LE and G showed clear diurnal
287 variations from March to October in both years, because LE and G in other months
288 was very small. The largest diurnal peaks of LE and G were 239.24 (September 2018)
289 and 123.45 (April 2019) W m^{-2} , respectively.

290 (Fig.4)

291 (Fig.5)

292 Energy partitioning for the three study years is shown in Table 4. Albedo in the GS
293 was similar to that in the NG, and annual albedo was 0.12 or 0.13 in this 3-year study.
294 Both L_d/L_u and $R_n/(S_d+L_d)$ were smaller in the NG than in the GS, annual L_d/L_u was
295 0.85 or 0.84 and annual $R_n/(S_d+L_d)$ was 0.18–0.19 in this 3-year study. In 2016, 2018,
296 and 2019, H/R_n in the NG was 0.69, 0.66, and 0.61, EF in the GS was 0.44, 0.42, and
297 0.40, respectively. Annual H/R_n (0.31–0.34) was comparable to annual EF (0.34–0.38)
298 in our study site. The ratio of G to R_n was relatively lower in different periods.

299 **Table 4**

300 A schematic representation of the energy fluxes in the GS, the NG, and the entire year
301 in the black locust plantation is shown in Fig. 6. Average S_d , S_n , L_d , L_u , R_n and LE
302 were larger in the GS than those in the NG. Average H was smaller in the GS than that
303 in the NG. And average G was positive and negative in the GS and NG, respectively.

304 **(Fig.6)**

305 *3.3 Evapotranspiration*

306 Daily evapotranspiration (ET) was usually smaller than 0.50 mm d^{-1} in the NG, and
307 peak values of daily ET appeared after P events, because dews on vegetation surface
308 and water on soil surface easily, as long as energy available, evaporates to the
309 atmosphere (Fig.7). In particular, the reference evapotranspiration (ET_0) was
310 relatively high, and ET was still relatively weak before the EG in the NG. In the EG,
311 the ET increased rapidly, and the ET_0 increased relatively slowly. In the MG, the ET_0
312 decreased slowly in general, and the general trend and day-to-day variation of ET_0
313 was not synchronous with the ET due to drought and P. In the LG, the ET decreased
314 with decreasing ET_0 . Annual ET was 497.16 mm, 503.19 mm, and 479.66 mm, and
315 annual $ET/(P+I)$ was 0.67, 0.86, and 0.85 chronologically for the three study years.
316 And ET/P was 2.67, 1.45, and 2.01 in the NG of 2016, 2018, and 2019, respectively.

317 **(Fig.7)**

318 The major factors controlling seasonal variation in daily ET were R_n , T_a , VPD, and
319 LAI in this study site (Table 5). The effect of T_a on daily ET was mainly indirect, via
320 LAI and VPD, the effect of LAI on daily ET was mainly direct. For R_n , direct effect
321 was smaller than indirect effect, mainly via LAI and VPD, in 2018 and 2019. For
322 VPD, direct effect was greater than indirect effect in 2018 and 2019. In addition, U in
323 2016 and SWC_{10} in 2018 had significant negative and positive correlation with daily
324 ET ($P < 0.01$), respectively.

325 **Table 5**

326 Yellow River Delta is influenced by meso-scale sea-land wind. The wind direction
327 range of 0 to 90° and 180° to 270° was used as typical sea wind and land wind,
328 respectively. Because canopy cover had an important effect on ET and severe drought
329 dramatically decreased ET, only ET and biophysical data in the MG of 2016 were
330 used to analyze the effect of wind direction on ET. As shown in Fig. 8, ET and
331 biophysical factors were affected by sea and land wind. Average λET under sea wind

332 (80.01 W m⁻²) was greater than that under land wind (67.59 W m⁻²), and average sea
333 and land wind direction was 57.76° and 205.57°, respectively (Fig. 8a and b). Average
334 R_n under sea and land wind was 139.99 W m⁻² and 155.37 W m⁻², respectively (Fig.
335 8c). After 8:00 h, VPD and T_a under land wind were relatively greater (Fig. 8d and e).
336 Between 8:00 h and 18:00 h, SWC₁₀ under sea wind was relatively greater, and around
337 noon, U under sea wind was relatively greater (Fig. 8f and g).

338 **(Fig.8)**

339 *3.4 Surface parameters*

340 Daily EF, K_c, α, g_s, and Ω had similar seasonal course, all of them were relatively
341 smaller in the NG, increased with canopy growth and development and decreased
342 with vegetation senescence in the EG (Fig.9a and c–f). Daily β displayed the opposite
343 course in comparison with the other surface parameters (Fig.9b). Daily β usually
344 decreased sharply and the other surface parameter usually increased dramatically after
345 P events. Average daily EF, K_c, α, g_s, and Ω reached maximum values of 0.42, 0.49,
346 0.48, 4.43 mm s⁻¹, and 0.14 in the MG of 2016, respectively. Average daily β was
347 5.94, 5.38, and 5.84 in the NG of 2016, 2018, and 2019, respectively (Table 6).

348 **(Fig.9)**

349 **Table 6**

350 The linear relationships were found between daily EF, K_c, α, g_s, and Ω and LAI with
351 goodness-of-fit values of 0.44–0.78 (Fig.10a and c–f). Daily β decreased
352 exponentially with increasing LAI, and goodness-of-fit value was 0.96 (Fig.10b). The
353 exponential relationship was found between daily α and g_s, daily α was insensitive
354 when daily g_s was greater than approximately 8 mm s⁻¹, and the asymptotic value of
355 daily α was 0.66 in this study (Fig.11).

356 **(Fig.10)**

357 **(Fig.11)**

358 **4. Discussion**

359

360 *4.1 Energy balance*

361 The energy balance closure is usually used to evaluate the performance of the eddy
362 covariance measurements. A comprehensive evaluation of energy balance closure
363 across 22 sites and 50 site-years in FLUXNET showed that slope values ranged from

364 0.53 to 0.99, intercept values ranged from -32.9 to 36.9 W m^{-2} , goodness-of-fit values
365 ranged from 0.64 to 0.96, and energy balance ratio values ranged from 0.34 to 1.69
366 (Wilson et al., 2002). Another comprehensive evaluation of energy balance closure
367 across 8 sites and 8 site-years in ChinaFLUX showed that slope values ranged from
368 0.49 to 0.81, intercept values ranged from 10.8 to 79.8 W m^{-2} , goodness-of-fit values
369 ranged from 0.52 to 0.94, and energy balance ratio values ranged from 0.58 to 1.00
370 (Li et al., 2005). Our results for energy balance closure in Table 3 are within the
371 ranges in FLUXNET and ChinaFLUX, comparable to the results in a hilly tea
372 plantation, east China (Geng et al., 2020) and a subalpine forest, southwest China
373 (Yan et al., 2017), and better than the results in a young plantation, north China (Ma et
374 al., 2018), indicating that the eddy covariance measurements were reliable in
375 estimating surface energy balance components in the study plantation. The reasons for
376 the energy unbalance may be related to sampling error, instrument bias, neglected
377 energy sinks, high/low frequency loss, advection, and many more complications
378 (Wilson et al., 2002). At our study site, the open canopy with understory vegetation
379 resulted in a patchy underlying surface, which might lead to the observed
380 inconsistency. The energy used for vegetation photosynthesis into biomass and used
381 for heat storage in air below the EC measurement level were excluded in our analysis.
382 The excluded amount might lead to an overestimation of available energy. Moreover,
383 the long- and short-wave radiation transmission at the soil-vegetation interface might
384 be altered by surface cover patchiness, and this phenomenon might alter the allocation
385 of available energy (Ma et al., 2018).

386 4.2 Energy partitioning

387 The mean of annual averages of L_d , L_u , S_d , and S_u over the three study years was
388 327.49 W m^{-2} , 383.82 W m^{-2} , 184.31 W m^{-2} , and 21.90 W m^{-2} in the study plantation
389 (Fig.6). Those means were comparable to a single cropping farmland at the same
390 latitude on the Loess Plateau (Gao et al., 2018). Compared to those over an alpine
391 meadow on the Tibetan Plateau (You et al., 2017), L_d and L_u were relatively greater
392 and S_d and S_u were relatively smaller. Solar altitude mainly controls the diel and
393 seasonal variations in S_d , which is also influenced by aerosols and clouds. And S_u is
394 mainly controlled by S_d and influenced by land cover, in particular snow. Annual
395 average albedo in our study site was smaller than that in an alpine meadow (0.31, You
396 et al., 2017) and a single cropping cropland (0.18, Gao et al., 2018), being consistent
397 with the widely accepted conclusion of albedo often lower in forest than cropland and

398 grassland (Zhu et al., 2014). Daily albedo had a peak in the EG at our site (Fig.3c), we
399 infer that the peak might be caused by the reflection of young leaf fluffs on light.
400 The peak become less obvious with the young leaf growing, during which fluffs
401 gradually fall off. Surface temperature mainly controls the diel and seasonal variations
402 in L_u , and L_d is mainly as influenced by air moisture and temperature. In the GS,
403 humid and warm air resulted in greater L_d/L_u at our site (Table 4). Annual average L_d/L_u
404 in the black locust plantation was comparable to that in a sub-alpine spruce forest
405 on the Tibetan Plateau (0.76, Zhu et al., 2014) and that in a mixed cropping system on
406 the Loess Plateau (0.84, Chen et al., 2016). Similar to previous studies (Zhu et al.,
407 2014; Chen et al., 2016), average $R_n/(S_d+L_d)$ was greater in the GS at our site, mainly
408 because of greater L_d/L_u in the same period. Annual average $R_n/(S_d+L_d)$ at our site was
409 comparable to the croplands on the Loess Plateau (Chen et al., 2016; Gao et al.,
410 2018).

411 As vegetation growth mainly dominated energy partitioning, H/R_n and EF in the GS
412 clearly differed from those in the NG (Table 3). In the NG, 3-year average H/R_n was
413 0.65, indicating that R_n was mainly portioned to H at our site as found in forest,
414 shrubland, grassland and cropland in previous studies (Zhu et al., 2014; Jia et al.,
415 2016; You et al., 2017; Gao et al., 2018). In the GS, EF was greater than H/R_n (Table
416 3), which indicates that LE the greatest component of R_n in the black locust
417 plantation. Similar to some previous studies on forest (Zhu et al., 2014; Ma et al.,
418 2018), EF was smaller than 0.5 in the GS at this site, the limited available water and
419 open canopy might result in this portioning. On an annual scale, EF at our site was
420 0.38, 0.37, and 0.34 in 2016, 2018, and 2019, respectively (Table 4). Those values
421 were greater than those in a sub-alpine forest (0.28, Zhu et al., 2014) and a young
422 plantation (0.15–0.17, Ma et al., 2018), but smaller than 0.66–0.71 for a hilly tea
423 plantation (Geng et al., 2020) and 0.57–0.60 for another sub-alpine forest on the
424 Tibetan Plateau (Yan et al., 2017). Because daily G was usually greater and smaller
425 than 0 in soil temperature increasing and decreasing period, respectively. Annual G/R_n
426 was very small at our site (Table 4) in consistency with previous studies in various
427 ecosystems (Zhu et al., 2014; Jia et al., 2016; You et al., 2017; Gao et al., 2018).

428 In the diurnal cycle of monthly average energy fluxes, LE was a major component of
429 R_n in May–September in 2016 and in August and September in 2018 and 2019. And H
430 was a major component of R_n in other months (Fig. 5). We suspect that different
431 vegetation growth and seasonal distribution of P should be responsible for this

432 phenomenon. At our site, LE was a little higher than 0 at night, indicating ET
433 occurred at night; H was a little lower than 0 at night, indicating the heat from the
434 atmosphere might be used for ET and offset the heat loss over soil and vegetative
435 surface due to long-wave radiation. Those are similar to previous studies in various
436 ecosystems (Wang et al., 2010; Zhu et al., 2014; Chen et al., 2016; Jia et al., 2016). At
437 our site, G was positive in the daytime and negative at night, respectively (Fig. 5), due
438 to energy into soil in the daytime and out of soil at night, and resulting in relatively
439 small daily G values (Fig.4d). As G was influenced by the shade of vegetation and
440 litter and seasonal variation in R_n , the amplitude of the diurnal cycle of G at our site
441 was between 6.88 (January 2018) and 72.84 (June 2016) $W m^{-2}$, comparable to that in
442 a sub-alpine spruce forest (Zhu et al., 2014), and usually smaller than that in cropland,
443 grassland and shrubland (Gao et al., 2018; Jia et al., 2016; Gu et al., 2005), indicating
444 the measurement of G in the high vegetation may be less important than in the low
445 vegetation on a 30-min time scale.

446 4.3 Evapotranspiration

447 Annual ET (479.66–503.19 mm) at our site was comparable to that in a sub-alpine
448 forest (Zhu et al., 2014) and an urban-forest ecosystem, north China (Xie et al., 2016),
449 smaller than that in an evergreen broad-leaved forest, south China and a poplar
450 plantation, north China (Xiao et al., 2013), and greater than that in a temperate mixed
451 forest, northeast China (Xiao et al., 2013) and a young plantation (Ma et al., 2018).
452 Annual ET varied in different site must be related to meteorological factors,
453 vegetation properties and soil water conditions. The ratio of annual ET to P and I is a
454 key parameter to quantify the effect of land cover change on regional hydrology (Ma
455 et al., 2018). Annual ET/(P+I) was 0.67–0.86 at our site, being comparable to that in
456 other forest ecosystems (Xiao et al., 2013). And annual ET/(P+I) was smaller than 1 at
457 our site, indicating that the black locust plantation was generally going through the
458 process of salinity eluviation. However, cumulative ET was larger than cumulative P
459 in the NG at our site. This indicates that the NG was a process of salinity cumulation
460 in the black locust plantation. This also suggests that the irrigation was necessary to
461 mitigate the drought and salt stress for black locust growth in the EG.

462 Similar to most terrestrial ecosystems (Gao et al., 2018; Xiao et al., 2013), R_n and T_a
463 were also major meteorological factors controlling daily ET at our site, suggesting
464 that energy induces water vapor loss in the black locust plantation (Sun et al., 2019).
465 As with a coastal salt marsh ecosystem, east China (Huang et al., 2019), VPD was

466 also a major control on daily ET in the black locust plantation, this is mainly because
467 of relatively higher H_a in the coastal zoon (Fig. 2a), which influences water vapor
468 transport. As leaves transpire water, LAI had significant positive correlation with
469 daily ET at our site, and this was consistent with the result in a single cropping
470 cropland (Gao et al., 2018). Seasonal variation in daily ET_0 was not exactly consistent
471 with that in daily ET (Fig. 7), showing that the seasonal pattern of daily ET in the
472 black locust plantation was related to vegetation phenology, which indicates that the
473 seasonal pattern of daily ET was controlled by the vegetation growth process. And
474 seasonal variation in LAI should be the critical factor of seasonal variation in daily ET
475 during the different phenological stages of black locust. The effect of vegetation
476 phenology on ET was also assessed in a riparian *Tamarix spp.* stand, northwest China
477 (Yuan et al., 2014), and the result was similar to that in our study. However, daily ET
478 did not dramatically decrease after the noticeable drop of LAI in the MG of 2018 (Fig.
479 2e and 6b). This is mainly because that understory vegetation and soil surface got
480 more radiation, which resulted in higher understory vegetation transpiration and soil
481 evaporation after the canopy of overstory vegetation was damaged by a hailstorm. In
482 the same year, SWC_{10} had significant positive correlation with daily ET, this also
483 because the ratio of understory vegetation transpiration and soil evaporation to total
484 ET may be larger in this year, as top-layer soil water usually is the water source for
485 understory vegetation transpiration and soil evaporation. Therefore, we should pay
486 more attention to the interaction between understory and overstory vegetation in the
487 future. In 2016, U had significant negative effect on daily ET via LAI at our site
488 (Table 5), this is mainly because that general trend of U might be opposite with that of
489 LAI in the GS.

490 Though annual $ET/(P+I)$ was smaller than 1, drought still occurred in the black locust
491 plantation, as seasonal pattern of P was not uniform at our site (Fig. 2d), and salinity
492 stress would increase while drought. Similar to previous studies (Yue et al., 2019; Ma
493 et al., 2018), drought obviously inhibited daily ET (decreased by approximately 40%)
494 in 2019, which reduced the growth of black locust and resulted in smaller peak value
495 of LAI in the same year. Under the background of climate warming and drought
496 period extending on the North China Plain (Wang et al., 2017), the black locust
497 plantation in the Yellow River Delta may be up against more severe pressure to
498 survive in the future. According to the results reported by Ma et al. (2013), black
499 locust would die while its roots grow into groundwater, because of relatively higher

500 groundwater salinity content in the Yellow River Delta. As high ground water table of
501 1.4 to 2.2 m in this study site, the root system of the black locust plantation can
502 survive to 1.4 m depth of soil, and this limitation may weaken the drought resistance
503 of black locust. In addition, the Yellow River Delta is subsiding due to a combination
504 of factors (Liu et al., 2019), which may lead to shallower GD, and hence GD should
505 need more attention in the future.

506 Wind direction influenced ET in the black locust plantation at our site (i.e. ET under
507 sea wind was larger than that under land wind, Fig. 8a), being consistent with the
508 results in a coastal salt marsh ecosystem (Huang et al., 2019). However, the cause of
509 the phenomenon in the previous studies was different from that in our study. In this
510 previous study, T_a under sea wind was nearly equal to that under land wind, VPD was
511 relatively smaller under sea wind, and solar radiation along with U were relatively
512 larger under sea wind in the daytime, but solar radiation was the dominantly control
513 on ET variation in the daytime, which resulting in larger ET under sea wind (Huang et
514 al., 2019). In our study, R_n , T_a , and VPD were larger under land wind in the daytime,
515 only U and SWC_{10} was larger under sea wind around noon and in the daytime,
516 respectively (Fig. 8b–g). We suspects that ET under sea wind was larger at our site,
517 more likely because of larger SWC_{10} under sea wind in the daytime, indicating that
518 soil water was not sufficient all the time, and also implying that sea wind might
519 usually occur after P events.

520 4.4 Surface parameters

521 Seasonal variations in daily EF, β , K_c , α , g_s , and Ω of the black locust plantation were
522 similar to those in previous studies (Gao et al., 2018; Jia et al., 2016; Zhu et al., 2014).
523 Daily EF and β were the important surface parameters of energy partitioning, and
524 daily EF exhibited the opposite pattern from daily β in the MG (Fig. 9a and b).
525 Average daily β in the MG at our site was larger than that in a single cropping
526 cropland and a hilly tea plantation (Gao et al., 2018; Geng et al., 2020), and smaller
527 than that in an alpine meadow (You et al., 2017) and a semi-arid shrubland, northwest
528 China (Jia et al., 2016). Daily K_c is an important surface parameter for planning
529 irrigation system and estimating ET in cropland (Guo et al., 2020), and this parameter
530 has been attracted much attention in natural ecosystems in recent years (Yuan et al.,
531 2014; Yang and Zhou, 2011). Average daily K_c in the MG at our site was smaller than
532 that in a desert-oasis region, northwest China (Zhang et al., 2016), and larger than that
533 in a temperate desert steppe in Inner Mongolia, China (Yang and Zhou, 2011). Daily

534 α , g_s , and Ω are the bulk surface parameters, used to help assess the effect of
535 biophysical factors on ET (Jia et al., 2018). Average daily α in the MG at our site was
536 around 0.50 (Table 6), which reflects available soil water in the root zone of black
537 locust was insufficient. Average daily g_s in the MG in the black locust plantation was
538 smaller than that in a hilly tea plantation and a subalpine forest with larger ET (Yan et
539 al., 2017; Geng et al., 2020), and previous study had proved the higher ET is often
540 associated with larger g_s in various vegetation types (Zhang et al., 2016). Average
541 daily Ω in the MG at our site was relatively smaller (0.12–0.21, Table 6), comparable
542 to that in a young plantation (Ma et al., 2018), and larger than that in a sub-alpine
543 spruce forest (Zhu et al., 2014). The smaller daily Ω indicates that the atmosphere and
544 canopy were coupled, and VPD was an important meteorological factor controlling
545 ET in the black locust plantation (Table 5; Jia et al., 2018).

546 Daily EF, α , g_s , and Ω increased with increasing LAI and daily β decreased with
547 increasing LAI at our site (Fig.10), which is consistent with other studies (Jia et al.,
548 2016; Ma et al., 2018). Daily K_c increased linearly with increasing LAI at our site,
549 which agreed with the same parameter of a riparian *Tamarix spp.* stand (Yuan et al.,
550 2014), indicating that ET was mainly contributed by transpiration through leaves as
551 quantified by LAI without a threshold, and implying that smaller LAI might be a
552 reason for relatively smaller ET in the black locust plantation. And daily K_c usually
553 increased exponentially with increasing LAI in cropland with larger LAI associated
554 with higher ET (Zhang et al., 2016). Abiotic factors (e.g., soil moisture and VPD) also
555 influenced surface parameters (Jia et al., 2016), and this implies that the day-to-day
556 fluctuations and general trends of seasonal variations in surface parameters were
557 mainly controlled by abiotic factors and LAI, respectively, at our site. The effects of
558 LAI on surface parameters illustrate that vegetation growth played a key role in
559 energy partitioning, ET estimating, and land surface development in the black locust
560 plantation.

561 The logarithmic curve between g_s and α at our site is consistent with other results
562 from various ecosystems (Jia et al., 2016; Ma et al., 2018; Gao et al., 2018), indicating
563 that strong physiological and phenological regulation of energy partitioning and ET in
564 the black locust plantation. At our site, daily g_s increased with increasing daily g_s until
565 the threshold daily g_s (ca. 8 mm s⁻¹; Fig.11), which indicates ET was strongly
566 influenced by g_s when daily g_s was smaller than 8 mm s⁻¹. A theoretical study on a
567 fully developed canopy indicated that α was insensitive to g_s when g_s was larger than

568 16 mm s⁻¹ (McNaughton and Spriggs, 1986; Gao et al., 2018). The asymptotic value
569 of daily α at our site was 0.66 (Fig.11), which was smaller than the results in many
570 ecosystems with larger LAI and higher ET (Gao et al., 2018; Yan et al., 2017; Geng et
571 al., 2020). The smaller asymptotic value of daily α and the daily g_s threshold found in
572 our study were possibly due to the open canopy coupled with drought and salinity
573 stress in the black locust plantation.

574

575 **5. Conclusion**

576

577 This study investigated 3-year observation of energy partitioning and ET over a black
578 locust plantation in the Yellow River Delta. At our site, L_d offset 84%–85% of L_u , S_u
579 accounted for 12%–13% of S_d , and the ratio of R_n to downward radiation was 18%–
580 19%. In the GS, LE was the largest component of R_n ; in the NG, H was the dominant
581 component of R_n in the black locust plantation. The seasonal variation in daily ET
582 were mainly controlled by R_n , T_a , VPD and LAI in this study. The black locust
583 plantation was generally going through the process of salinity eluviation, and spring
584 irrigation was necessary to mitigate the drought and salt stress for black locust growth
585 in the EG. The phenology of black locust influenced the seasonal variation in daily
586 ET, mainly via LAI. And ET under sea wind was larger than that under land wind,
587 mainly because SWC_{10} was larger under sea wind in daytime. Seasonal patterns of
588 daily EF, β , K_c , α , g_s and Ω were mainly controlled by LAI, and the threshold value of
589 daily g_s was approximately 8 mm s⁻¹ in the black locust plantation. The open canopy
590 and drought and salinity stress played an important role in energy partitioning, ET and
591 surface development at our site. These results will be a valuable reference for
592 sustainable managements of black locust plantation in the Yellow River Delta.

593

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597 **References**

598

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775 **Figure Captions**

776 **Fig. 1** The location of study site in the Yellow River Delta (a) and the observation
777 tower (b).

778 **Fig. 2** Seasonal variations in biophysical factors in 2016, 2018 and 2019. Biophysical
779 factors are (a) air temperature (T_a), air relative humidity (H_a), (b) vapor pressure
780 deficit (VPD), (c) wind speed (U), groundwater depth (GD), (d) precipitation (P),
781 irrigation (I) soil water content at 10 cm depth (SWC_{10}) and 40 cm depth (SWC_{40}), (e)
782 leaf area index (LAI). NG: non-growing season, EG: early growing stage, MG: mid
783 growing stage, LG: later growing stage.

784 **Fig. 3** Seasonal variations in (a) downward/upward shortwave radiation (S_d/S_u),
785 downward/upward longwave radiation (L_d/L_u), (b) net shortwave/longwave radiation
786 (S_n/L_n), and (c) albedo in 2016, 2018 and 2019.

787 **Fig. 4** Seasonal variations in (a) net radiation (R_n), (b) sensible heat flux (H), (c) latent
788 heat flux (LE), and (d) soil heat flux (G) in 2016, 2018 and 2019.

789 **Fig. 5** Diurnal cycle of the monthly average R_n and its components in 2016, 2018 and
790 2019.

791 **Fig. 6** Schematic representation of the energy fluxes ($W m^{-2}$) in the growing season,
792 the non-growing season, and the entire year in the black locust plantation.

793 **Fig. 7** Seasonal variations in (a) reference evapotranspiration (ET_0), and (b)
794 evapotranspiration (ET) in 2016, 2018 and 2019.

795 **Fig. 8** Diurnal cycle of average (a) ET, (c) R_n , (d) T_a , (e) VPD, (f) SWC_{10} and (g) U
796 under (b) sea ($0-90^\circ$) and land ($180-270^\circ$) wind conditions in the mid growing
797 season, 2016.

798 **Fig. 9** Seasonal variations in daily (a) evaporative fraction (EF), (b) Bowen ratio (β),
799 (c) crop coefficient (K_c), (d) Priestley–Taylor coefficient (α), (e) surface conductance
800 (g_s), and decoupling coefficient (Ω) in 2016, 2018 and 2019. Data for rainy days are
801 not shown.

802 **Fig. 10** Relationships between LAI and (a) daily EF, (b) β , (c) K_c , (d) α , (e) g_s and (f)
803 Ω in the growing season at our site. The dependent variables were bin-averaged into
804 $0.2 m^2 m^{-2}$ LAI increments. *Represents a significance level of $p < 0.01$.

805 **Fig. 11** Relationship between daily α and g_s in the growing season at our site. When g_s
806 $< 7 mm s^{-1}$, the dependent variables were bin-averaged into $0.5 mm s^{-1} g_s$ increments;
807 when $7 mm s^{-1} < g_s < 11 mm s^{-1}$, the dependent variables were bin-averaged into $2 mm$
808 $s^{-1} g_s$ increments; when $g_s > 11 mm s^{-1}$, the dependent variables were bin-averaged

809 into $10 \text{ mm s}^{-1} \text{ g}_s$ increments. *Represents a significance level of $p < 0.01$.

810

811 **Table 1.** List of measured items and instruments in the black locust plantation.

Observations	Height/depth (m)	Model, manufacturer	Accuracy	Data logging
Latent (LE)/ sensible heat flux (H), friction velocity (U_*)	19.5	IRGASON, Campbell Scientific Inc., Logan, UT, USA	$\pm 2\%$	30 min avg. ^a
Air temperature (T_a)/ relative humidity (H_a)	18	HMP45C, Vaisala Co., Ltd., Helsinki, Finland	$\pm 0.2\text{ }^\circ\text{C}/3\%$	30 min avg.
Downward (S_d)/upward shortwave radiation (S_u), downward (L_d)/upward (L_u) longwave radiation	1.5; 18	CNR4, Kipp & Zonen B.V., Delft, Netherlands	$<1\%$	30 min avg.
Wind speed (U)/direction (WD)	18	034B, Met One Instruments Inc., Grants Pass, OR, USA	$\pm 1\%/4^\circ$	30 min avg.
Soil water content (SWC) ^b	0.1; 0.4	CS650, Campbell Scientific Inc.	$\pm 1\%$	30 min inst. ^c
Soil heat flux (G) ^d	0.1	HFP01SC, Hukseflux B.V., Delft, Netherlands	$\pm 2\%$	30 min avg.

812 ^a 30 min interval average of samples taken at 0.1s sampling interval.

813 ^b calibrated by oven drying method.

814 ^c instantaneous value of 10 s sampling interval at 30 min record interval.

815 ^d included soil heat storage above the plate.

816 **Table 2.** Start date and end date of each phenological stage in the growing season in
 817 the black locust plantation.

Year	Period	Start Date	End Date
2016	Early growing stage	6 April	10 June
	Mid growing stage	11 June	20 September
	Later growing stage	21 September	14 November
2018	Early growing stage	11 April	1 June
	Mid growing stage	2 June	20 September
	Later growing stage	21 September	19 November
2019	Early growing stage	15 April	2 June
	Mid growing stage	3 June	20 September
	Later growing stage	21 September	19 November

818

819 **Table 3.** Characteristics of energy balance and annual ratio of $\Sigma(\text{LE}+\text{H})/\Sigma(\text{R}_n-\text{G})$ in 2016, 2018, and 2019. LE: latent heat flux; H: sensible heat
820 flux; R_n : net radiation; G: soil heat flux.

Year	Slope	Intercept (W m^{-2})	Data number	R^2	Annual ratio
2016	0.57	12.05	15707	0.85	0.68
2018	0.57	12.50	12633	0.86	0.69
2019	0.57	12.11	14881	0.86	0.68

821

822 **Table 4.** Energy partitioning in the growing season, the non-growing season, and the entire year for 2016, 2018, and 2019. L_d : downward
 823 longwave radiation; L_u : upward longwave radiation; S_d : downward shortwave radiation; EF: evaporative fraction.

Year	Period	Albedo (S_w/S_d)	L_d/L_u	$R_n/(S_d+L_d)$	H/R_n	EF(LE/R_n)	G/R_n
2016	Growing season	0.12	0.88	0.22	0.20	0.44	0.009
	Non-growing season	0.12	0.80	0.13	0.69	0.15	-0.064
	Entire year	0.12	0.85	0.18	0.31	0.38	-0.007
2018	Growing season	0.12	0.87	0.23	0.23	0.42	0.008
	Non-growing season	0.14	0.82	0.13	0.66	0.16	-0.049
	Entire year	0.13	0.85	0.19	0.33	0.37	-0.005
2019	Growing season	0.11	0.87	0.23	0.26	0.40	0.009
	Non-growing season	0.12	0.81	0.14	0.61	0.16	-0.038
	Entire year	0.12	0.84	0.19	0.34	0.34	-0.003

825 **Table 5.** Path analysis between daily ET and net radiation (R_n), wind speed (U), air temperature (T_a), vapor pressure deficit (VPD), soil water
 826 content at 10 cm depth (SWC_{10}), and leaf area index (LAI) in the black locust plantation.

Year	Variable	Correlation coefficient	Direct effect	Indirect effect					
				R_n	U	T_a	VPD	SWC_{10}	LAI
2016	R_n	0.72*	0.39		0.00	-0.08	0.12	-0.07	0.35
	U	-0.17*	0.04	-0.03		0.04	0.01	0.01	-0.25
	T_a	0.73*	-0.15	0.19	-0.01		0.06	-0.07	0.70
	VPD	0.53*	0.19	0.25	0.00	-0.05		-0.04	0.17
	SWC_{10}	-0.10	0.29	-0.09	0.00	0.03	-0.03		-0.31
	LAI	0.75*	0.79	0.17	-0.01	-0.13	0.04	-0.11	
2018	R_n	0.67*	0.14		0.00	0.12	0.20	0.04	0.16
	U	-0.05	0.02	0.01		-0.03	0.00	0.01	-0.05
	T_a	0.72*	0.19	0.10	0.00		0.16	0.05	0.23
	VPD	0.61*	0.32	0.09	0.00	0.09		0.02	0.10
	SWC_{10}	0.33*	0.24	0.03	0.00	0.04	0.02		0.01
	LAI	0.62*	0.30	0.08	0.00	0.15	0.10	0.01	
2019	R_n	0.70*	0.27		0.00	0.02	0.25	0.00	0.16
	U	-0.09	0.02	-0.02		-0.01	-0.03	0.04	-0.09
	T_a	0.76*	0.04	0.15	0.00		0.22	-0.02	0.38
	VPD	0.73*	0.41	0.17	0.00	0.02		-0.02	0.15
	SWC_{10}	0.01	0.19	0.00	0.00	0.00	-0.04		-0.15
	LAI	0.65*	0.46	0.09	0.00	0.03	0.14	-0.06	

827 *Represents a significance level of $p < 0.01$.

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829

830 **Table 6.** Average daily EF, Bowen ratio (β), crop coefficient (K_c), Priestley–Taylor coefficient (α), surface conductance (g_s), and decoupling831 coefficient (Ω) in early, mid and later growing stage and average daily EF, β , K_c , α , g_s , and Ω during the non-growing season in 2016, 2018, and

832 2019.

Year	Period	EF	β	K_c	α	g_s (mm s ⁻¹)	Ω
2016	Early growing stage	0.33	1.43	0.37	0.41	2.91	0.09
	Mid growing stage	0.47	0.34	0.62	0.56	6.98	0.21
	Later growing stage	0.41	1.19	0.42	0.42	3.16	0.11
	Non-growing season	0.19	5.94	0.16	0.16	1.08	0.06
2018	Early growing stage	0.33	1.28	0.40	0.41	3.30	0.10
	Mid growing stage	0.42	0.61	0.49	0.48	4.43	0.14
	Later growing stage	0.43	1.07	0.42	0.44	2.93	0.11
	Non-growing season	0.21	5.38	0.17	0.19	1.19	0.07
2019	Early growing stage	0.39	0.83	0.38	0.45	2.68	0.08
	Mid growing stage	0.40	0.66	0.47	0.48	3.71	0.12
	Later growing stage	0.39	1.34	0.34	0.37	2.28	0.07
	Non-growing season	0.19	5.84	0.15	0.16	1.01	0.06

