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Willows for environmental projects: A literature review of results on evapotranspiration rate and its driving factors across the genus *Salix*

Chloé Frédette[a,b] ✉ , Michel Labrecque[b] , Yves Comeau[c] & Jacques Brisson[a,b]

[a] Département de sciences biologiques, Université de Montréal, C.P. 6128, succ. Centre-ville, Montreal, Quebec, Canada H3C 3J7, chloe.fredette@umontreal.ca, jacques.brisson@umontreal.ca

[b] Institut de recherche en biologie végétale, 4101 Sherbrooke East, Montreal, Quebec, Canada H1X 2B2, michel.labrecque@umontreal.ca

[c] Department of Civil, Geological and Mining Engineering, Polytechnique Montréal, 2900 Édouard-Montpetit blvd, Montreal, QC H3T 1J4, yves.comeau@polymtl.ca

✉ **Corresponding author:** Chloé Frédette

4101 Sherbrooke East, Montreal, Quebec, Canada H1X 2B2

chloe.fredette@umontreal.ca

1 **Abstract**

2 Willows are increasingly used for a wide range of environmental projects, including

3 biomass production, leachate treatment, riparian buffers and treatment wetlands.

4 Evapotranspiration (ET), assumed to be high for most willow species used in

5 environmental projects, affects hydrological cycles and is of key interest for project

6 managers working with willows. Here, we present a comprehensive review of ET rates

7 provided in the literature for the genus *Salix*. We aim to summarize current knowledge of

8 willow ET and analyze its variability depending on context. We compiled and analyzed

9 data from 57 studies, covering 16 countries, 19 willow species and dozens of cultivars.

10 We found a mean reported ET rate of 4.6 ± 4.2 mm/d, with minimum and maximum

11 values of 0.7 and 22.7 mm/d respectively. Although results reported here varied

12 significantly between some species, overall interspecific standard deviation (± 3.6 mm/d)

13 was similar to intraspecific variation (± 3.3 mm/d) calculated for *S. viminalis,* suggesting

14 a greater influence of the growing context on ET than species identity. In terms of

15 environmental and management variables, water supply, fertilization and contamination

16 were identified as driving factors of ET across willow species. Effects of root age,

17 experimental context, planting density and soil type were more nuanced. Our findings

18 provide synthetic data regarding willow ET. We encourage practitioners who use ET data

19 from the literature to be aware of the main drivers of ET and to consider the influence of

20 the experimental aspects of a study in order to interpret data accurately and improve

21 project planning.

22

1. Introduction

26   Willows (genus *Salix*) are comprised of hundreds of species, distributed throughout the

27   world, but mostly in the northern hemisphere (Argus, 1986). They can take various

28   growth forms, from small shrubs to large trees. Although some species are adapted to

29   harsh or arid conditions, they more often colonize humid or wet habitats (Dickmann and

30   Kuzovkina, 2014). Aside from traditional pharmaceutical and artisanal uses, willows also

31   have many environmental and energy applications. For some uses, they are produced in

32   short rotation coppice plantations (Zsuffa *et al*., 1984; Gullberg, 1993; Volk *et al*., 2006;

33   Guidi *et al*. 2013), sometimes irrigated with wastewater (Lachapelle-T. *et al*., 2019),

34   sewage sludge (Dimitriou and Rosenqvist, 2011) or leachate (Duggan, 2005). They are

35   thus suitable for use in prevention of leaching of hazardous wastes in evapotranspirative

36   plantations (ET covers; Rüth *et al*., 2007; Mirck and Volk, 2009), phytoremediation of

37   contaminated soils (Witters *et al.,* 2009; Grenier *et al*. 2015), treatment wetlands

38   (Gregersen and Brix, 2001; Curneen and Gill, 2014), and urban and agricultural

39   catchment runoff systems (Hénault-Éthier *et al*. 2017) or even to prevent erosion (Yoder,

40   1993). Over time, *Salix* species performance has been enhanced by selection and genetic

41   improvement programs (Lindegaard and Barker, 1997; Kopp *et al*., 2001; Smart and

42   Cameron, 2008), and most environmental projects involving willows have used selected

43   or improved cultivars rather than natural species.

44   Along with high biomass production, willows are known for their high water

45   consumption. Little information is available to enable comparison of willow transpiration

46 (T) with that of other woody species, but it is generally accepted that willow species used

47 for biomass production and other wetland or riparian occurring species in a temperate

48 climate transpire much more than other herbaceous crops (Personn, 1997). Although a

49 high evapotranspiration (ET) rate is essential for some of the uses cited above, such as ET

50 covers, it may be undesirable in other cases. In Europe, for instance, rapid expansion of

51 willow plantations for biomass production has raised concerns about potential

52 disturbance of natural hydrological systems (Dimitriou *et al.,* 2009). An example of such

53 disturbance has been documented in Australia, where willow introduction is thought to

54 have increased water shortage problems, and caused other environmental damage (Doody

55 and Benyon, 2011); willows are now even considered an invasive and prohibited species

56 in some parts of the world (Doody *et al*., 2014; Marttila *et al.,* 2018; Tang *et al.,* 2018).

57 ET is also an important factor to consider for the design and performance evaluation of

58 treatment wetlands (Beebe *et al*., 2014; Białowiec *et al*., 2014), which are sometimes

59 planted with willows. ET rate thus represents an essential design and operational tool for

60 practitioners working with willows, as well as an important factor to consider before

61 extensive introduction of willows in a given area.

62 ET measurement is complex and requires substantial time, as well as human, technical

63 and financial resources (Allen *et al*., 2011). In most cases, it is far more practical to use

64 values provided by the scientific literature to plan a project involving willows. However,

65 ET rate is highly context-specific, meaning that results obtained in a given set of

66 conditions might not be relevant to practitioners working in a different environment.

67 Indeed, ET is driven by meteorological conditions, plant related factors and

68 environmental parameters (Allen *et al.,* 1998), all of which can vary greatly from one

69 site/study to another. Meteorological factors can be partially controlled when plants are

70 grown in greenhouses, but are otherwise mainly governed by geographic location. For

71 environmental projects, willows tend to be treated as a single species, but the numerous

72 cultivars derived from many individual species and their respective morphology and

73 physiology are obviously important plant factors that can influence ET variation across

74 the *Salix* genus. Some environmental conditions can be at least partially controlled, such

75 as irrigation, fertilization and coppicing cycle. These factors are most likely to vary

76 depending on the purpose of the study and management decisions, and thus represent a

77 wide range of possible growing conditions. Although not related to the ET process itself,

78 the method used for measurement or estimation of ET is also known to greatly influence

79 results, as most methodological approaches require a high level of expertise and rigor to

80 provide reliable results (see Allen *et al.*, 2011, for a detailed review on that matter).

81 Presentation of methodology and results is also highly heterogeneous, which makes

82 comparing studies difficult. In the end, it can prove rather challenging to find suitable ET

83 information regarding a willow cultivar for a given environmental purpose.

84 The first objective of this paper was to gather the available ET rate data published for

85 willow species and synthesize this information in a standardized and comparable way.

86 The second objective was to assess the variation of ET across the genus and identify the

87 main drivers of this variability. This review aims to improve our global knowledge of ET

88 potential in rapid growing woody species like willows, and point out opportunities for

89 further research on this topic. Finally, this review should serve as guide for practitioners

90 working with willows for environmental projects to improve irrigation planning,

91 treatment wetland sizing and other decision-making that requires willow ET information.

92

2. Methods

2.1 Literature review

Evapotranspiration is, in fact, the combination of both plant T and soil evaporation (E_s). Willows are woody plants that are often fast growing, and thus develop a considerable leaf area. According to Shuttle and Wallace's energy partitioning model (1985), high leaf area index (LAI) implies a reduced Es proportion in ET. This is illustrated in numerous studies presented in this review, as we see the E_s to ET ratio decline in the growing season as the willow leaf cover becomes established (Grip et al., 1989; Iritz et al., 2001; Lindroth et al., 1994; Persson, 1997). For the purpose of this review, T results have been considered along with ET results, under the premise that willow T is a fair estimate of total ET. We are, however, aware that T might represent an under-estimation of the true ET value.

2.1.1 Articles selection

A literature review was performed using the keywords "*willow* OR *Salix*" AND "*evapotranspiration* OR *transpiration* OR *water use*", in the Web of Science, Scopus and Google Scholar databases. We selected peer-reviewed articles presenting original results of ET (or T) rates, or data allowing easy calculation of ET rate (*e.g.* irrigation and drainage volumes). We excluded studies presenting data related to ET but not detailed enough to calculate a daily rate (*e.g.* instantaneous rate of T, water-use efficiency), ET results from plant communities including other species than willows and studies measuring willow T at laboratory or growth chamber scale. For instance, for an ET rate provided as an amount of water transpired by a leaf area per unit of time, the leaf area

115 index as well as the typical daily transpiration period (*e.g.* hours of sunlight per day)

116 would have been necessary to convert the results to a mm/d unit. For studies presenting

117 only stemflow results, scaling-up calculations based on sap wood area and various

118 mathematical equations would have been necessary to convert stemflow into transpiration

119 results. ET rates had to be convertible to mm/d units (see section 2.2), and obtained under

120 experimental conditions that could be described by at least 3 of 8 experimental variables

121 selected for results analysis and interpretation, as detailed in section 2.3 (willow species,

122 age of plantation/root system, experimental conditions, water supply, planting density,

123 dominant soil type, fertilization and contamination).

124 *2.1.2 ET data transformation*

125 As expected, the ET rates gathered from the literature review varied in absolute value, but

126 also in unit of expression. For comparison purposes, we converted each result to a

127 millimeter per day basis (mm/d), the most common unit for ET rate. For studies that

128 presented total ET values for a given period, we divided these values by the number of

129 days of the experiment. As some authors reported ET rates only graphically, some results

130 were extracted from these graphs. For studies that reported ET rates in terms of volume

131 per plant, the conversion in mm/d was calculated based on the soil area of the plant

132 container (*e.g.* lysimeter surface area) or soil area covered by the plant (inferred from

133 canopy area or planting density).

134 **2.2 Comparative analysis based on experimental variables**

135 To interpret the variability of ET rates across studies testing various factors, we used an

136 approach based on a semi-quantitative classification of the experimental and

137 environmental conditions under which the studies were performed. These "conditions",

138 also referred to as "variables" or "factors", include both independent variables and

139 conditions imposed by the authors. We decided to exclude typical meteorological and

140 climatic ET limiting factors such as temperature, solar radiation, wind and water vapor

141 pressure deficit (VPD) of our analysis, since the effect of those factors on potential ET

142 (pET) are already well described in scientific literature related to ET and should mainly

143 be driven by geographic location. We then considered plant related variables and

144 environmental and management variables; each variable was divided into several

145 qualitative or semi-quantitative levels (Table 1).

146   *2.2.1. Plant variables*

147 Different plant species have a different T rate according to their intrinsic

148 ecophysiological properties and environment (Bohnert *et al.,* 1995). Including the plant

149 species in a variance analysis would potentially reveal a difference in ET rate between

150 species of the willow genus. T rate should also vary for a given species according to plant

151 growing conditions. To estimate if differences between species were more likely due to

152 taxonomical differences or to growing conditions, we evaluated inter and intraspecific ET

153 rate variation (α_{inter} and α_{intra} respectively). An interspecific variation greater than

154 intraspecific variation would suggest an influence of the species itself on ET rate. ET rate

155 is closely linked to growth rate, which itself is thought to decrease with age (Willebrand

156 and Verwijst, 1993). Consequently, we also considered the age of the plantation as a

157 potential explanatory factor for ET variation. We divided this variable into 3 categories:

158 the establishment year (*first year*), for willows grown from cuttings that have to develop

159 their root system, *young* and *mature* willows (Table 1). Willows with a root system of 5

160   years of age or more were considered as *mature* because we supposed that, at this point,

161   the root system should be well established.

162   *2.2.2. Environmental and management variables*

163   In every study, willows are grown under various conditions determined by the

164   experimenter (management variables) or naturally present on the study site

165   (environmental variables). Some variables like planting density or soil type can be either

166   managed or naturally determined depending on the experimental context. Other factors

167   like water supply can be both determined and random, when plants are provided with

168   rainfall and controlled irrigation at the same time, for instance. Fertilization and

169   contamination are normally deliberately provided to the plants.

170   The *experimental context* variable was chosen to represent the spatial scale of the willow

171   stand, the *plantation* level being the largest scale and the *mesocosm* the smallest. The

172   levels of this variable also indicate if the experimental unit is an open (*floodplain* and

173   *plantation*) or closed (*treatment wetland* and *mesocosm*) system in terms of hydrological

174   and soil processes.

175   Water supply is typically considered a limiting factor for ET (Payero *et al.*, 2008; Novák,

176   2012). Not all references provided sufficient methodological information to calculate the

177   actual volume of water provided to the plants. Thus, we classified this variable with semi-

178   quantitative levels (Table 1) according to the global volume of water available or

179   provided to the plants. When water supplies were quantified, we calculated the mean

180   daily volume provided to plants and classified it as follows: < 5 mm/d was considered

181   *low*, 5 to 10 mm/d *medium* and > 10 mm/d *high*. When insufficient quantitative

182   information was provided, water supply was considered *low* when the only water input

183 was rain (in semi-arid to arid climate) or when water stress was imposed or reported by

184 the authors; *medium* when input was rain in humid to very humid climate, when a small

185 amount of artificial irrigation was added to rainfall or when the water table was

186 controlled to a high but non-saturating level; and *high* when high levels of irrigation were

187 provided or when the water level saturated the media (*e.g.* in a treatment wetland or a

188 floodplain).

189 Planting density can affect willows negatively, by increasing competition between

190 individuals for soil resources, or positively, by maximizing light interception (Willebrand

191 and Verwijst, 1993). We categorized a density of 1 plant per m^2 or less as *low*. The

192 *medium* level included a density from 1 to 4, based on common values used for willow

193 plantation (Willebrand *et al*., 1993; Volk *et al*., 2006, Walle *et al*., 2007). A density

194 higher than 4 plants per m^2 was considered *high*.

195 We also selected soil type as a variable because of its influence on soil water potential

196 and water availability (Novák, 2012). The relation between water and soil depends on the

197 type of soil particles and can act on two levels. The first level, which is referred to in

198 agriculture as field capacity, determine the soil water content after gravitational drainage

199 has occurred. The more sand is contained in the soil, the less water will remain in the soil

200 at field capacity because of the low attraction between sand particles and water

201 molecules, while an increase in clay proportion, and furthermore in organic content,

202 increases soil water retention capacity (Waller and Yitayew, 2015). However on a second

203 level, at the same water content, water will be more easily available to plants in a sandy

204 soil, were water potential is higher (due lower water molecules attraction) than in a

205 clayey or organic soil water that have lower water potential due to the matrix attraction

206 (Waller and Yitayew, 2015). Because the substrates used in the studies reviewed were

207 never composed of one type of particles alone, we classified this variable according to the

208 dominant type of particles in the media (Table 1). We also treated gravel media

209 separately and excluded articles with a very specific soil type (to avoid having a level of

210 the category with only one observation) or that did not provide information on the media.

211 The effect of fertilization and contamination were treated for their direct effect on plant T

212 (Feldhake *et al.*, 1983; Trapp *et al.*, 2000). They were treated as a binomial variable

213 (presence or absence; Table 1) because of the disparities between the type of nutrient

214 sources and contaminants and their method of addition. Landfill leachate was a particular

215 case, and was considered here as both a source of nutrients and contamination. Indeed,

216 willow can use ammonia (typically present in leachate) as a source of a nutrient which

217 can become a toxicant when its concentration is too high. Other leachate constituents

218 such as chlorinated compounds can have a similar toxic effect.

219 *2.3 Statistical analysis*

220 When a study tested more than one level of at least one variable, it was considered to

221 have more than one result (n) in the variance analysis. For example, a study measuring

222 ET of two species with two different fertilization levels accounted for four individual

223 results (n=4) in the analysis. When results were reported for many replicates of the same

224 treatment, only the mean value was considered. Using this approach, we built a data base

225 by associating each individual ET rate result to the appropriate level of each variable

226 from Table 1. We then proceeded to the comparative analysis, which consisted of a

227 variance analysis (ANOVA) using R statistical software (version 3.5.1). The model tested

228 in the analysis included all variables, in order to consider their simultaneous effect on ET

229 rate. The ET results followed a Fisher distribution, and a log transformation was used to

230 normalize the data prior to statistical analysis. Missing information for some variables

231 (no observation for one or more variables for a given ET result) yielded an unbalanced

232 statistical plan. However, the most commonly used type of ANOVA (type I) has the

233 effect of giving significantly different results depending on how the variables are ordered

234 in the model when provided with an unbalanced data set. Therefore, we decided to

235 perform a type II ANOVA, which typically gives higher P values (less significant results)

236 but is not influenced by the order of the variables in the model. Type II ANOVAs are

237 generally suggested as the best substitute for a type I analysis for unbalanced data

238 (Langsrud, 2003). We also used a correlogram to illustrate possible interactions between

239 the variables of the comparative analysis, except for the variable *plant species*, which is

240 composed of more than fifteen levels. Following the comparative analysis, we also

241 performed linear regression analysis between ET results and both planting density

242 (plants/m^2) and water input (mm/d) for the articles where quantitative information was

243 provided for those two variables. For all analyses, a P value lower than 0.05 was

244 considered significant. Finally, α_{intra} was calculated as the standard deviation of the

245 results associated with the most frequently studied species (*S. viminalis*, n=53), while

246 α_{inter} was calculated as the standard deviation between the average ET rate reported for

247 each specie (n=18).

248

249 **3. Results**

250 *3.1 Article selection and data transformation*

251   Out of the 800+ articles analyzed, 57 met our selection criteria. The studies covered the

252   period from 1986 to 2019 and were from 16 countries, although half (27) originated from

253   Northern Europe. Results were obtained for natural willow species (21 articles) and

254   cultivars (36 articles), each articles testing one to four species and up to 6 different

255   cultivars, for a total of 19 species studied (Table 2). Plants growing conditions ranged

256   from wild to cultivated/controlled, stressed to non-stressed. Overall, 20 studies reported

257   results in mm/d, 26 studies were in mm for a given period (most of the time, per season),

258   and the remaining 9 studies required additional calculations to express results in mm/d.

259   Sixteen articles presented plant T results only.

260   At least 4 of the 8 variables considered for categorization of the results were provided in

261   each article (Table 2). Information regarding planting density was missing in 6 articles,

262   and root system age in six other articles, while both types of information were missing in

263   13 studies. However, this information was mainly missing from studies conducted on

264   natural willow stands, where age and density are heterogeneous and more difficult to

265   document. The soil type turned out to be very difficult to categorize due to the wide range

266   of substrates used and the ambiguous nature of the dividing line between clayish and

267   sandy soil (*e.g.* a soil with 50% sand particles and 40% clay particles was considered as

268   *sand* even if it varies greatly from pure sand). After extracting information from all the

269   studies according to the different levels of the categorical variables (see Section 2.2 and

270   Table 1), 110 ET rate results could be treated individually (n = 110, Table 2). Thirty-five

271   articles presented results obtained with homogenous experimental variables (1 study =

272   1 result), and the studies that tested the most factors resulted in nine individual results

273   (Table 2; Martin and Stephens, 2006). Some studies tested different treatments but were

274 still considered as one result in our analysis because variation between the treatments

275 could not be captured with our variable categorization (*e.g.* 3 irrigation rates tested, but

276 all below 5mm/d, which is considered *low* for the variable *water supply*)

3.2 Comparative analysis

278 According to the 110 observations, ET rates ranged from 0.7 up to more than 20 mm/d.

279 The lowest rate was reported for T (rather than ET), expressed on an annual basis, of *S.*

280 *fragilis* grown in a gravelly/sandy soil on the banks of a stream (Marttila *et al.*, 2017),

281 while the highest average rate of 22.7 mm/d measured over one growing season by water

282 balance for the species *S. miyabeana* 'SX67' with a mature root system and grown in a

283 treatment wetland with high water supply, medium planting density, organic soil and low

284 contamination and fertilization (Frédette *et al*, 2019). Mean reported ET rate across all

285 studies was 4.6 mm/d (± 4.5), with about 80% of reported ET rates ranging from 0 to 10

286 mm/d. We observed some trends regarding factors interactions (Figure 1). For example,

287 we observe that willows growing in *floodplain* are almost systematically associated with

288 *mature* trees, *medium* to *high* water supply, *high* planting density and natural conditions

289 (no fertilization or contamination), that *first year* cuttings and *young* willows are mainly

290 used in *mesocosms* studies while most *mature* trees studied are in *plantation*, or that

291 fertilization was more frequently associated with *treatment wetlands* and *mesocosms*

292 rather than *floodplains* or *plantations*.

3.2.1 Plant variables

294 While 30 and 40 results were reported for *first year* and *young* willows respectively, only

295 13 pertained to willows with a *mature* root system (Figure 2). The age of the root system

296 did not significantly affect the results, even though fresh stems newly developed from

297 cuttings tended to be associated with slightly lower ET than *young* or *mature* willow

298 plants (4.2 mm/d compared to 5.3 and 5.0 mm/d respectively; Figure 2). Sixteen of the 19

299 species were associated to 5 results or less, compared to the most studied species, *S.*

300 *viminalis*, which was associated to 53 results. Three articles did not provide the exact

301 taxonomic identity of the willow studied (*Salix* sp.). There was a significant difference of

302 the results according to species (Figure 2). However, α_{intra} for *S. viminalis* (3.3 mm/d)

303 was very similar to variation between species mean ET rate (α_{inter} = 3.2 mm/d). *Salix*

304 *amygdalina*, *S. exigua* and *S. psammophila* were the three species with the lowest mean

305 ET rate (< 2 mm/d), while *S. babylonica*, *S. cinerea*, *S. goodgingii, S. miyabeana* and *S.*

306 *nigra* (all cultivars combined) had the highest (> 7 mm/d; Figure 2).

307   *3.2.2 Environmental and management variables*

308 The majority of the articles reviewed studied willows growing either in mesocosms or in

309 plantations (Figure 3). The effect of experimental context on ET rates was not significant

310 (Figure 3). Nonetheless, *treatment wetlands* were generally associated with higher results

311 (7.9 mm/d on average), followed by *mesocosms* (5.7 mm/d), *floodplain* (3.6 mm/d) and

312 finally *plantation* results (2.9 mm/d; Figure 3). Water supply was found to be a

313 significant experimental variable (Figure 3), with *low* water supplies associated to the

314 lower results (2.4 mm/d on average), compared to *medium* and *high* water supply (5.0

315 and 7.0 mm/d, respectively; Figure 3). Almost half of the results were measured or

316 calculated for willows that were poorly supplied with water (n=47; Figure 3).

317 Furthermore, we found a significant linear correlation between daily water input and

318 daily ET rate for open systems (r^2 = 0.7, Figure 4). The planting density did not

319 significantly explain ET rate variations in our factorial analysis (Figure 3). However,

320   average ET rates were the same for *medium* and *high* planting density (5.4 mm/d), but

321   slightly lower at *low* density (3.2 mm/d; Figure 3). Linear regression of ET rate over

322   planting density did not show a clear trend either (Figure 5), but the few results reported

323   at very high planting density suggest the existence of a threshold, after which ET is

324   limited (here estimated to be approximately 5 plants/m^2; Figure 5). Regarding the type of

325   soil in which willows were grown, most results were reported for sandy soils, followed

326   by clayey soils. No significant effect of soil type was found (Figure 3), but the following

327   average ET rate gradient could be observed: in organic soil (6.1 mm/d) > in clayey soil

328   (5.3 mm/d) > in sandy soil (4.9 mm/d) > in gravel (1.6 mm/d). We should mention that

329   only 3 results were reported for gravel substrate. Finally, fertilization and contamination

330   both had a significant effect in the comparative analysis (Figure 3). Studies that used

331   some kind of fertilization treatment reported ET rates 40% higher on average compared

332   to unfertilized willows (6.1 mm/d vs. 3.5 mm/d). On the contrary, ET rates were

333   generally lower in the presence of contaminants, although average rates were very similar

334   (4.6 mm/d in the presence of contamination compared to 4.7 mm/d in non-contaminated

335   conditions; Figure 3).

336

4. Discussion

338   Our review shows that mean ET rates in willows are generally below 10 mm/d, but may

339   rise well over that value, reaching up to 23 mm/d. According to a factorial analysis

340   performed on 110 ET rate results from 57 articles, we found that water supply,

341   fertilization and contamination significantly affected ET rates. We identified a strong

342   correlation between daily water input and ET rate in open systems. The effects of plant

343   age, experimental context, and planting density were not statistically significant, although

344   some trends could be observed. Soil type in fact was less important than the other

345   variables, when their simultaneous effect on ET was tested. Willow species seemed to

346   significantly affect ET rates, but α_{inter} and α_{intra} variation of ET were equivalent.

347   Variation of T rate between species is to be expected, because its regulation mechanisms

348   are not the same for every taxa (Sperry, 2000). These mechanisms are generally adapted

349   to the plant environment (Bohnert *et al.*, 1995), a good example being xerophytic species,

350   which display various ways of preventing water loss through T (Fahn and Cutler, 1992).

351   This could explain why *S. psammophila*, a willow species adapted to dry environments

352   (Xiao *et al.*, 2005), had one of the lowest ET rates, while *S. nigra*, a water dependent

353   species (Pezeshki *et al.*, 2007), had the highest. Overall, different willow species had

354   different ET rate ranges, but in the end there were so few studies on each species and so

355   many other factors that varied between studies that we cannot conclude that taxonomical

356   identity dictates mean ET rate in the willow genus. Furthermore, the fact that ET

357   variation between willows of the same species (*S. viminalis*) was the same as that

358   between different species suggests that species identity is not the most important factor in

359   ET variation across the willow genus, particularly for species adapted to similar

360   environments (*e.g.* wet habitat). However, willow cultivars developed in breeding

361   programs can promote high T rates for environmental applications like phytoremediation

362   (Smart *et al.*, 2005) or promote increased water use efficiency (WUE) and tolerance to

363   water limitation for biomass production (Karp *et al.*, 2011). This could explain the high

364   variability of ET in the *S. viminalis* species, which in this review is comprised of more

365   than 20 genetically different cultivars.

366   Regarding the age of the willow root system, our hypothesis was that plants in their *first*

367   *year* – the establishment year, as well as *mature* shrubs, which should have a lower

368   growth rate, would be associated with lower ET rates compared to young, fast growing

369   plants. Indeed, we observed lower ET for plants newly developed from cuttings, but not

370   for *mature* shrubs. However, it appears that the mean average ET rate for mature trees

371   was driven up mainly by the results of one study (Frédette *et al.* 2019); when those

372   results are set aside, mean ET rate for mature trees drops from 5.9 mm/d to 2.4 mm/d.

373   This difference could be explained by the fact that ET results in Frédette *et al*. (2019)

374   were obtained from a treatment wetland with a high water supply, while all the other

375   results from mature shrubs came from plantations with a low water supply. Furthermore,

376   willows in the Frédette *et al*. study were recently coppiced, while most of the other

377   studies were conducted on willows with much older stems. Coppicing of willows is

378   known to help keep the plants in a juvenile, and thus more productive, state and it could

379   then be responsible of those high ET rates. A decrease in biomass production with time

380   has been documented for willows in the past, even in a coppicing system (Willebrand *et*

381   *al*., 1993), but our analysis did not allow us to demonstrate this pattern. Further studies

382   should be conducted on this specific issue to provide clearer answers.

383   Our findings suggest that ET rate is greater in closed and relatively small-scale systems

384   (treatment wetlands and mesocosms) than in open and full-size systems (floodplain and

385   plantations). In open systems, ET is higher in floodplains, where the water table (and thus

386   water availability) is generally high and some flooded conditions can even occur, than in

387   plantations, where water may be limited and will drain to lower soil horizons. In

388   comparison, in closed systems like treatment wetlands or some mesocosms, water supply

389   is often equal to or greater than plants' water demand, meaning that water is not a

390   limiting factor and ET occurs at a rate closer to maximal pET. Furthermore, pET can be

391   exceeded in small scale willow stands by processes like an "oasis" or "clothesline" effect

392   (Allen *et al*., 1998; Frédette *et al*., 2019; Dotro *et al*., 2017). An oasis effect is the result

393   of a difference in temperature between willows and their surroundings, due to the cooling

394   effect of ET, which increases available energy to willows by a heat advection effect (Hao

395   *et al*., 2016; Dotro *et al*., 2017). The clothesline effect increases ET on the edges of the

396   willow stand because of enhanced wind influence, as a result of the height difference

397   between willows and the surrounding vegetation (Brix and Arias, 2011; Dotro *et al*.,

398   2017). Both those effects could partially explain higher ET rates reported in mesocosms

399   and treatment wetlands. Another aspect of the experimental context variable is that it

400   shared many associations with other variable levels (Figure 1). Thus, mesocosms were

401   mainly associated with younger willows and medium to high planting density; treatment

402   wetlands generally had a high water supply, medium to low planting density and organic

403   soil; floodplains had a medium to high water supply, high planting density, sandy or

404   clayish soil, unfertilized and uncontaminated environment; and finally, plantations were

405   associated with low to medium water supply, medium planting density, various soil

406   types, but mainly uncontaminated conditions. When considered as the only explanatory

407   variable, experimental context significantly explains ET variation (p<0.001). On the one

408   hand, the experimental context might provide a global indicator of ET rate combining

409   many environmental and management variables, but on the other hand, it might be

410   interesting to replace it by finer variables (*e.g.* experimental unit area and permeability)

411   to add precision to a global analysis.

412 Of all the chosen variables, water supply was one of the most significant driving factors

413 of ET rate variation. Along with meteorological conditions, water is a direct limiting

414 factor for ET, and the impact of water stress on ET rates is generally well described in the

415 ET literature (Sperry, 2000; Bohnert *et al*., 1995). This review highlights a strong

416 correlation between water supply and ET rate across the willow genus. For open systems

417 where water supplies could be quantified, this factor alone could explain most of the ET

418 rate variation. However, according to the same correlation analysis, the difference

419 between water supply and ET rate increased with increasing water supply, illustrating

420 that the less water is limiting, the more other factors become limiting. This relation may

421 not hold in a closed system, as a lesser effect of water availability on ET has been

422 demonstrated in closed versus open systems (Rana and Katerji, 2000). For example,

423 Guidi and Labrecque (2010) found no increase in ET rate for *S. viminalis* '5027' with

424 very high irrigation rates, compared to "normal" irrigation, in a pot experiment. As

425 previously discussed, water use strategy may also vary from one species to another,

426 depending on its natural environment but also on its breeding strategy. Most of the

427 species studied here are naturally associated with humid habitats, and therefore do not

428 require a very efficient water regulation mechanism, which has given willows their

429 "water-wasting" plant reputation.

430 Generally, increasing planting density of a crop will also increase biomass yield, until an

431 optimal threshold density is reached; beyond that threshold, a higher density will not

432 produce more biomass due to competition for resources such as for water or light (Assefa

433 *et al*., 2018; Ngouajio, 2001; Willebrand and Verwijst, 1993). As willow biomass is

434 thought to be closely linked to ET (Martin and Stephens, 2006; Marmiroli *et al*., 2012;

435 Białowiec *et al*., 2007), the same threshold hypothesis could apply to ET rate. Our results

436 strongly suggest that the planting density at which willow ET is maximal is higher than 1

437 plant/m^2 studies using this density systematically reported lower ET rates. No significant

438 differences were found between *medium* and *high* planting density, but plotting ET rates

439 with the corresponding density suggests a threshold around 5 trees/m^2. However, only 12

440 of the 57 articles reviewed reported results for densities higher than this potential

441 threshold. Furthermore, yield increases for willow have been documented at a density as

442 high as 11 plants/m^2 (Bullard *et al*., 2002).

443 In addition to water supply, water availability (often expressed as soil water potential)

444 can affect ET, and the type of soil impacts water potential for a given water supply

445 (Rawls *et al*., 1982). However, the soil effect, through attraction force between soil

446 particles and water, can act on two levels, as described in section 2.3.2 of the present

447 manuscript. This dual effect may explain why we did not observe significantly different

448 ET rates according to soil type in this review. Presence of organic matter in the soil even

449 adds another level of interaction by providing additional nutrients to plants, which can

450 increase growth and, consequently, ET rate, which is supported by the slightly higher ET

451 rates reported here for *organic* soils. For the three studies in which *gravel* was used as a

452 substrate, a high ET rate would have been expected, because the substrate was constantly

453 kept saturated with water that should be highly available because of gravel's physical

454 properties. However, low ET rates were measured, probably due to late season

455 measurements in one case (Jing *et al.* 2010), water contamination in another (Białowiec

456 *et al*., 2003) and ET rates reported on an annual basis (including low ET rates in winter)

457 in the last (Marttila *et al*., 2017). This and the previous explanations highlight the

458   simultaneous effect of multiple factors and suggest that soil type alone is not a strong

459   explanatory variable for ET variation.

460   As expected, fertilization increased willow ET, probably by increasing growth rate. Only

461   one study used fertilization as the main treatment variation, and it reported a 96%

462   increase in ET due to fertilization (Guidi *et al*., 2008). Pistocchi *et al.* (2009) also

463   reported a 51% increase of willow ET when switching from low to high fertilization. For

464   some studies, the variation in the fertilization treatment was due to amendments to the

465   substrate in various forms, such as compost, mechanical-biological pretreated waste

466   material, sewage sludge or other forms of organic matter addition (Rüth *et al*., 2007;

467   Białowiec *et al*., 2007; Martin and Stephens, 2006). Despite the presence of other

468   interacting factors, the *fertilized* treatment in these studies was always associated with

469   slightly higher ET rates. Interestingly, most of the articles that were associated with

470   fertilization were, in fact, exposing willows to various types of wastewater, mainly

471   landfill leachate or from domestic and agricultural source. These types of water did

472   contain nutrients such as nitrogen and phosphorus, but also contained harmful

473   compounds such as chloride and sulfate, high ammonium and salt concentrations, and

474   metalloids, particularly when leachates were the source of fertilization. A good

475   illustration of the dual effect of this type of effluent is provided by Białowiec *et al*.

476   (2003), describing how a low concentration of landfill leachate had a positive effect on

477   willow ET but increasing concentrations became deleterious to the plants. Conversely,

478   Curneen and Gill (2014) reported an increase in ET when using primary (more

479   concentrated) instead of secondary (less concentrated) effluent from domestic

480   wastewater, probably because the beneficial effect of the high levels of nitrogen and

481 phosphorus in this type of wastewater exceeded other potentially negative water

482 characteristics. This may also explain why average ET rate was similar for contaminated

483 and uncontaminated results; 9 of the 14 studies that measured ET rates in contaminated

484 conditions provided fertilized conditions at the same time. When testing chloride

485 contamination only, Stephens (2000) clearly demonstrated the negative impact of

486 increasing chloride concentration on ET. Furthermore, ET rate is frequently used as a

487 toxicity indicator in lab tests, due to its sensitivity to increasing pollutant concentration

488 (Trapp *et al*, 2000, Clausen *et al*., 2018). Therefore, contamination and fertilization

489 should be considered together to accurately judge their influence on ET in view of their

490 compensatory effect on each other.

491 ET is a complex process, and despite the numerous factors evaluated here, there are

492 additional variables that were not analyzed numerically but that could provide a better

493 understanding of ET results. As previously mentioned, biogeographical variation along

494 with meteorological conditions are important factors, and a synthetic and theoretical

495 explanation of those variables can be found in ET literature (see for example Holdridge,

496 1947 and Allen *et al.*, 1998). For example, higher temperatures and smaller seasonal

497 variations correlate with high ET rates reported in regions as such as Arizona (Nagler *et*

498 *al*., 2003) and Louisiana (Conger and Portier, 2001). In this review, we also found that

499 some results reflected coupling and decoupling of willow T with atmosphere and its

500 associated water vapor pressure deficit, which is variable along with plant development

501 (Mirck and Volk, 2009). Otherwise, ET rates show obvious seasonal variation that is

502 accentuated in northern countries, which have shorter growing periods and little to no ET

503 during winter. ET also varies according to phenology and leaf development during the

504　growing period. Although this concept might seem obvious, we consider it pertinent for

505　practitioners planning a project based only on published ET values. According to most of

506　the articles reviewed here, maximum leaf area of willows is generally reached in late

507　summer months, and ET rate is maximal from July to September in the northern

508　hemisphere. This phenological pattern is quite different from that in typical grass species,

509　which develop their total aerial biomass earlier in the season (Persson, 1997). Therefore,

510　the willow crop coefficient (K_c; *i.e.* ratio between willow ET and a reference well-

511　watered grass surface ET) has proven to be very high late in the season (Curneen and

512　Gill, 2016; Persson, 1995; Irmak *et al.*, 2013; Guidi *et al*., 2008). The crop coefficient is a

513　thus a very useful tool for irrigation planning or project design, and being aware of the

514　temporal variation of willow K_c is an asset.

515　Finally, although the methodological approach adopted by researchers to measure ET has

516　no direct influence on ET processes, it can contribute to greater ET measurements and

517　calculations. Allen *et al*. (2011) suggested an error range from 5 to 200% in ET

518　measurement, depending on the method used, experimenter experience and training, as

519　well as equipment reliability. Water balance, when performed in a closed system where

520　water fluxes are controlled (*e.g.* lysimeter, treatment wetlands) should yield the most

521　reliable results; this type of method was the most commonly used among the articles

522　reviewed here. When used alone, open water balance can be imprecise due to a high

523　degree of uncertainty regarding leakage and runoff processes. Sap flow approaches are a

524　subset of methods that estimate plant T based on water transport in stems. The method

525　itself presents a number of potential sources of error (Allen *et al*., 2011), and requires

526　extensive calculations and precautions to scale up the ET values from stems to a whole

527   tree stand (Green *et al*., 2003; Grime and Sinclair, 1999). It can therefore be considered a

528   difficult method that requires great expertise and experimental rigor (Allen *et al.*, 2011).

529   Still, the general homogeneity of sapwood in fast-growing willow shrubs developed for

530   coppice plantations makes scaling up results for them easier and more reliable than for

531   other shrubs or trees with more complex arborescence patterns. Modelling methods

532   comprise several distinct approaches, including micrometeorological methods such as

533   energy balance or Penman methods, and models based on different variables like leaf or

534   soil parameters, or a combination of modelling approaches. In this review, we found that

535   studies based on modelling approaches tended to provide low ET rates and less variation

536   across studies than the two previous approaches. This could be due to the fact that most

537   of these modelling studies were conducted in plantations (associated here with lower ET

538   rates) or to over parameterization of models that tend to limit ET in additive or even

539   multiplicative ways. Still, modelling studies are often based on field measurements and

540   serve as practical and sometimes more realistic tools for irrigation planning.

541

5. Conclusions

543   Overall, willow ET rates reported in scientific literature varied mainly according to plant

544   species, water supply, fertilization and contamination, although species influence remains

545   unclear. It can be hypothesized that environmental/experimental factors have more

546   influence on ET of willows that share similar plant life-forms (*e.g.* fast-growing shrubs

547   naturally found in wet habitats) than taxonomical identity. Water supply seems to be the

548   most limiting factor among those investigated here. In open systems and until pET is

549   reached, there is a positive linear relation between water supply and ET rate. The

550 projected use of the willows (*e.g.* ET cover, treatment wetland, biomass production)

551 informs us on many aspects of the growing conditions, such as the relative water

552 availability and the scale of the willow stand. This variable alone could thus be used to

553 estimate whether ET should be expected to be high or low, although it does not allow

554 precise estimation of ET. A planting density of two to five trees per square meter should

555 be favored to maximize ET and avoid excessive competition. Based on the present

556 review, the effect of soil type on ET remains unclear but may not be one of the most

557 important driving factors. Fertilization and contamination levels provided to plants

558 should be compared to estimate their global effect on plant growth and ET, particularly in

559 cases where willows are irrigated with wastewater or leachate. Finally, biogeographic

560 location will always influence potential ET rate and should be considered by project

561 planners, in addition to the plants, environmental and experimental issues pointed out in

562 this review. Future research on willow ET should focus on 1) specifying the root or stem

563 age effect on ET, 2) confirming the optimal density for ET processes, as well as 3) testing

564 whether, under a given set of growing conditions, species or cultivar identity has a

565 significant effect on ET or not.

566

569

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WILLOWS FOR ENVIRONMENTAL PROJECTS: A LITERATURE
REVIEW OF RESULTS ON EVAPOTRANSPIRATION RATE AND
ITS DRIVING FACTORS ACROSS THE GENUS SALIX.

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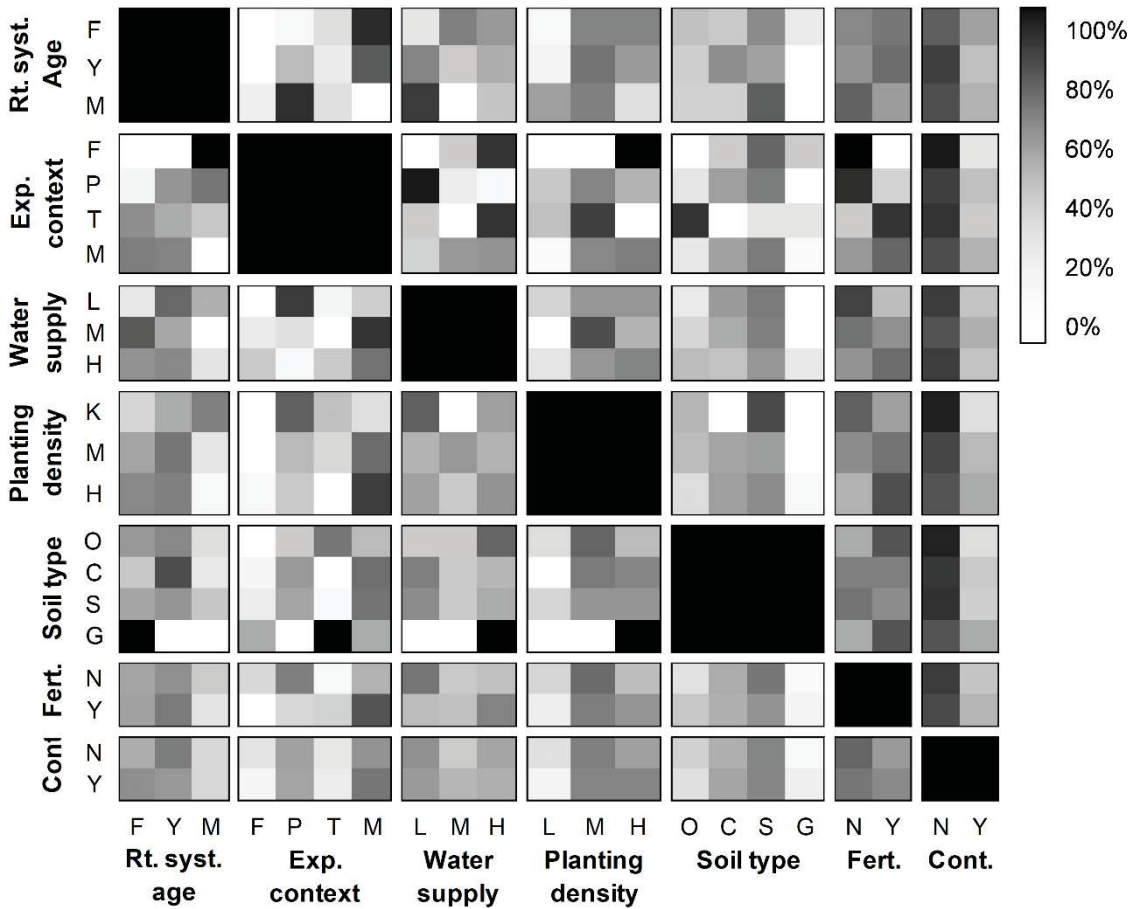
Figure 1. Correlogram illustrating the frequency (%) of association between the levels of nine variables selected to explain the variation of evapotranspiration rate across the willow genus (*Salix* sp.). Darker colors indicate a frequent association between levels of two variables (black = 100%, *i.e.* levels always associated), while pale colors indicate that the levels of the two variables were not likely to be combined (white = 0%, *i.e.* levels never associated). The codes used for variables levels are detailed in table 1 of the present article.

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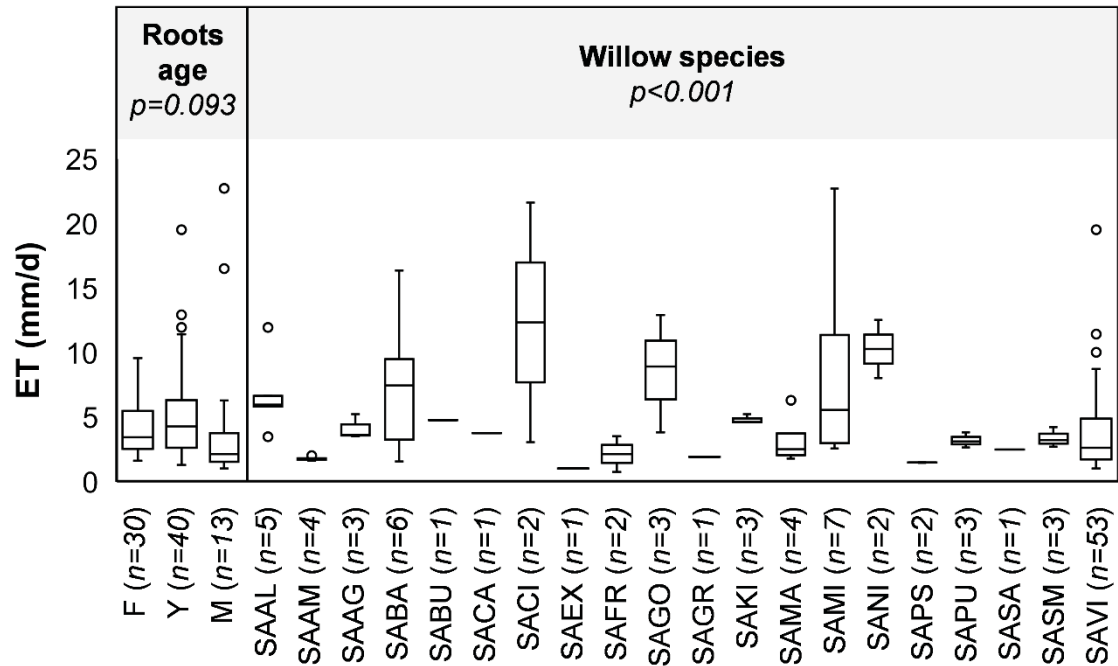
Figure 2. Mean evapotranspiration (ET) rates reported in 57 articles in 16 countries, according to plant related variables (root system age and species). Numbers in parenthesis (n) represent the number of average results considered for each variable level. The codes used for variables levels are detailed in table 1 of the present article. P values indicate if the variables affect significantly (α=0.05) ET results according to a Type II ANOVA analysis testing the simultaneous effect of 10 variables.

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Figure 3

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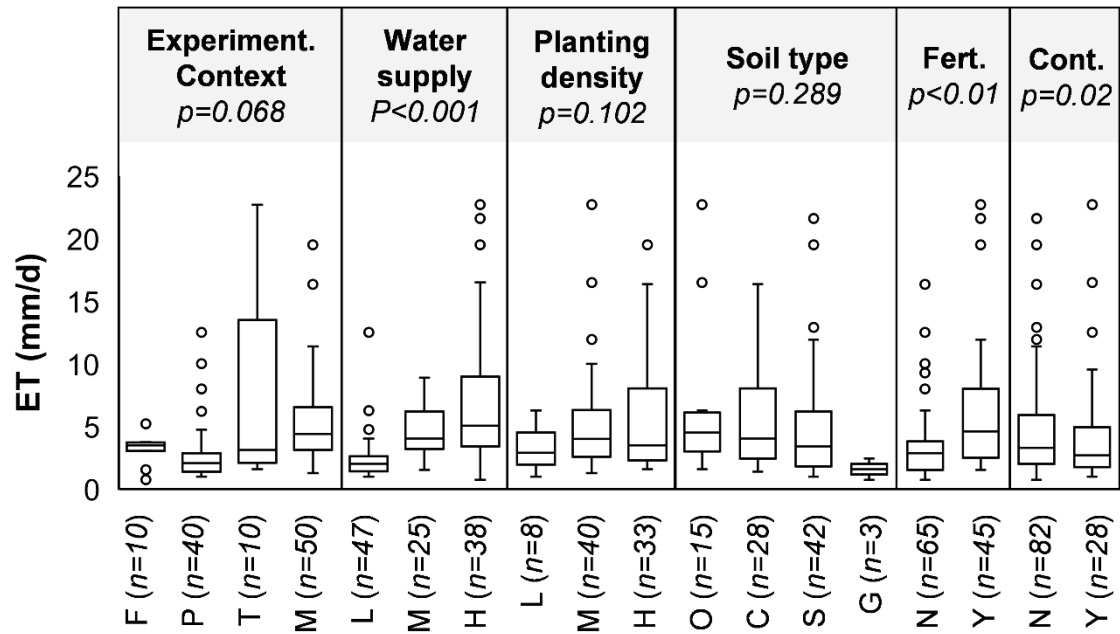
Figure 3. Mean evapotranspiration (ET) rates reported in 57 articles in 16 countries, according to experimental/management variables (experimental context, water supply, planting density, dominant soil type, fertilization and contamination). Numbers in parenthesis (n) represent the number of average results considered for each variable level. The codes used for variables levels are detailed in table 1 of the present article. P values indicate if the variables affect significantly (α=0.05) ET results according to a Type II ANOVA analysis testing the simultaneous effect of 10 variables.

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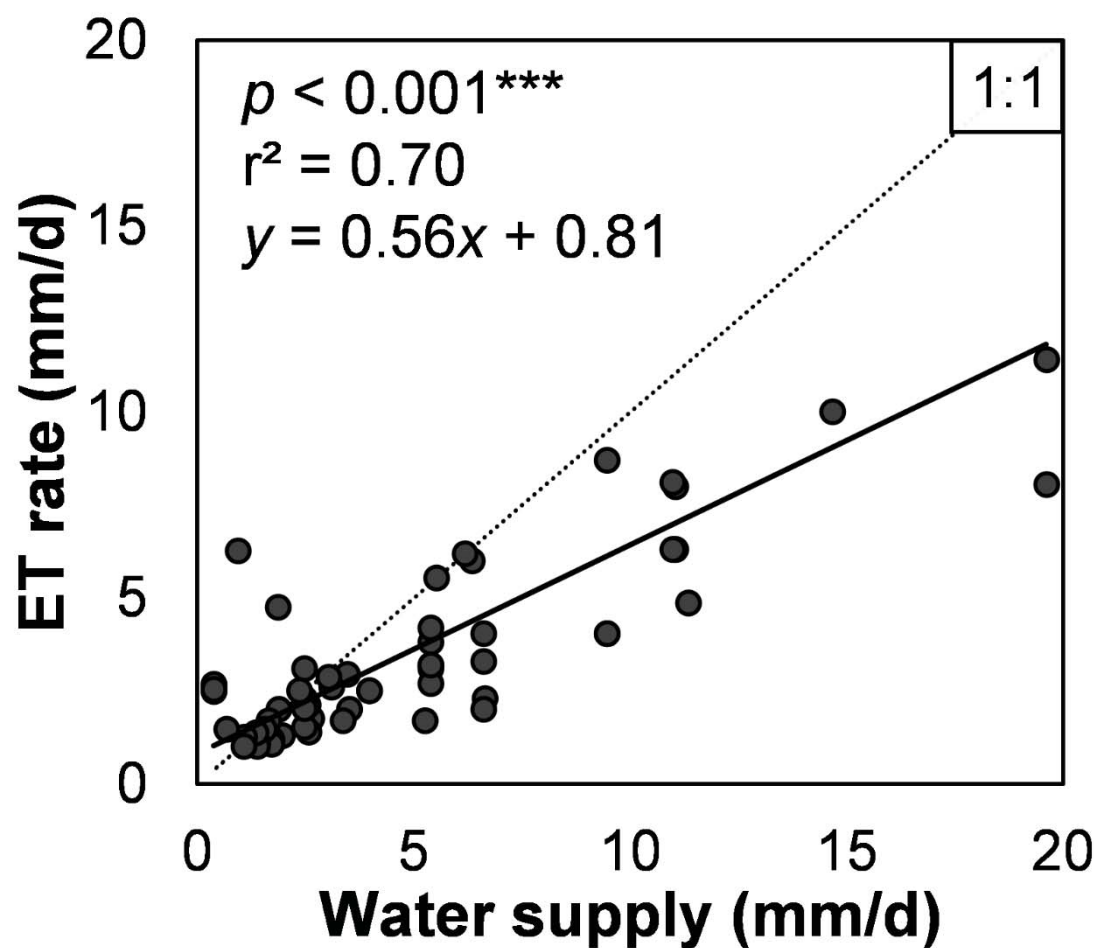
Figure 4. Summary of the linear regression between mean daily evapotranspiration rate of willows reported in scientific literature and the amount of water supplied daily, either by precipitation or irrigation ($n = 63$). Reference articles included in this analysis are detailed in Table 2 of the present article, and are comprised of studies of open systems with water table low enough to allow drainage.

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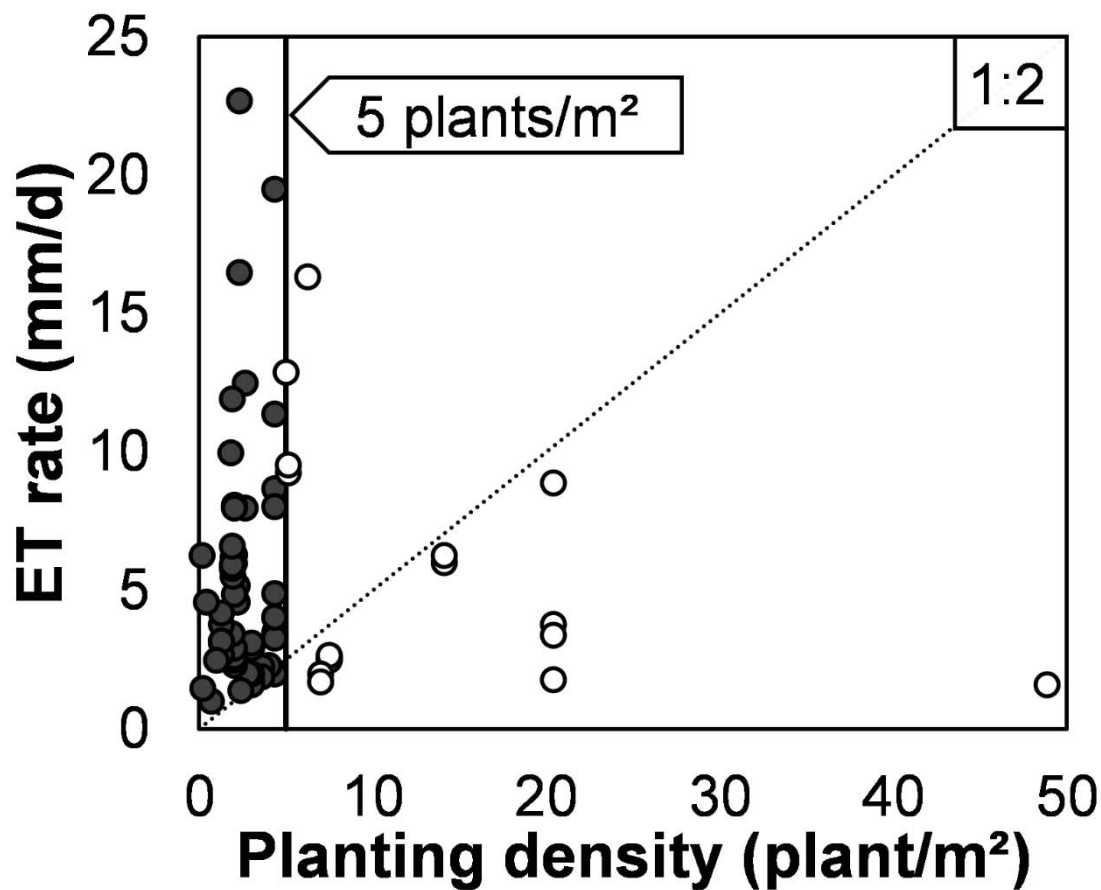
Figure 5. Mean daily evapotranspiration rate of willows reported in scientific literature in relation to planting density ($n = 75$). Reference articles included in this analysis are detailed in Table 2 of the present article. An arbitrary threshold (dashed line) for ET was drawn at a planting density of 5 trees per m^2.

Size: 1 column

Table 1. Summary of ten variables selected to categorize, compare and identify driving factors of willow (*Salix* sp.) evapotranspiration rates results found in the scientific literature.

Type	Variable	Levels	Description	Code
Plant variables	Willow species	19 species (see Table 2 for species listing and codes)		
	Age of plantation	First year	Establishment year	F
		Young	2 to 5 years old roots	Y
		Mature	> 5 years old roots	M
Environmental/management variables	Experimental context	Flood plain	Natural stands in wet habitat	F
		Plantation	Mand made plantation or natural stand in mesic to dry habitat	P
		Treatment wetland	Pilot and full-scale	T
		Mesocosm	Lysimeters and pots	M
	Water supply	Low	> 10 mm/d or saturated root zone	L
		Medium	5 to 10 mm/d or field capacity	M
		High	< 5mm/d or water deficit	H
	Planting density	Low	≤ 1 plants/m^2	L
		Medium	1 to 4 plants/m^2	M
		High	> 4 plants/m^2	H
	Dominant soil type	Organic	Significant organic matter content	O
		Clay	> 50% clay particles	C
		Sand	> 50% sand particles	S
		Gravel	> 50% gravel content	G
	Fertilization	Yes	Fertilizer, soil amendment or nutrient rich wastewaters	Y
		No		N
	Contamination	Yes	Soil or water contamination	Y
		No		N

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Table 2
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Table 2. Range of evapotranspiration rates (mm/d) reported in 57 articles for 19 different willow species (and various cultivars) in 16 countries, along with the corresponding information about plants, experimental and methodological variables. Results of transpiration only are indicated in parenthesis (T). Information missing about some variables is due either to non-reported information or to values that did not fitted the selected levels of a variable. Numerical value of water supply and planting density are detailed in parenthesis when available. The codes used for variables levels are detailed in table 1 of the present article. Each article tested one to nine experimental treatments (n), for a total of 110 mean results considered for comparative analysis.

Species 'cultivar'	Code	ET range (mm/d)	Age	Context	Water (mm/d)	Density (plant/m^2)	Soil	Fert.	Cont.	n	Country	Ref.
S. alba 'SI62-059'	SAAL	3.4-11.9	F, Y	M	M	M (1.9)	S	Y, N	N	4	Italy	1
S. alba 'SI62-059'	SAAL	4.6-7.0	Y	M	M	M (1.9)	S	Y	N	1	Italy	2
S. amygdalina	SAAM	0.6-2.3	F	M	H	H (48.8)	G	Y	Y	1	Poland	3
S. amygdalina	SAAM	1.0-3.0	F, Y	M	L, M (3.4-5.3)	H (7)	S	Y	Y	3	Poland	4
S. amygdaloïdes	SAAG	3.6-5.2	-	F	H, M	-	S	N	N	2	U.S.	5
S. amygdaloïdes	SAAG	3.5 (T)	-	F	H	-	S	N	N	1	U.S.	6
S. babylonica	SABA	1.5-6.6	-	F	H, M	-	-	N	N	2	Australia	7
S. babylonica	SABA	2.4	F	T	H	-	G	Y	N	1	China	8
S. babylonica	SABA	9.3-9.6	F	M	H	H (5.1)	C	Y, N	Y,N	2	Canada	9
S. babylonica	SABA	16.4	-	M	H	H (6.25)	C	N	N	1	U.S.	10
S. bujartica 'Germany'	SABU	4.8 (T)	Y	P	L (1.9)	-	C	N	N	1	Sweden	11

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Species	Code	ET										Country	Ref
S. caroliniana	SACA	3.8	M	F	H	-	-	N	Y	1	U.S.	12
S. cinerea	SACI	21.6	-	T	H	-	S	Y	N	1	Belgium	13
S. cinerea	SACI	3.0	-	F	H	H	C	N	N	1	Czechoslovakia	14
S. exigua	SAEX	0.7-1.6	M	P	L (1.1)	L (0.7)	S	N	N	1	U.S.	15
S. fragilis	SAFR	3.5	-	F	H	-	-	N	N	1	Australia	16
S. fragilis	SAFR	0.7	-	F	H	-	G	N	N	1	New-Zeland	17
S. gooddingii	SAGO	2.5-8.9 (T)	F	M	M	H (20.4)	S	Y	Y, N	2	U.S.	18
S. gooddingii	SAGO	12.9 (T)	Y	M	H	H (5.0)	S	N	N	1	U.S.	19
S. gordejevii	SAGR	1.9 (T)	-	P	L	H (3.6)	S	N	N	1	China	20
S. kinuyanagi 'Kimura'	SAKI	4.6-5.4	F	M	H	M (2.2)	S	Y, N	Y, N	2	New-Zealand	21
S. kinuyanagi 'Kimura'	SAKI	4.6	Y	M	H	L (0.4)	S	Y	Y	1	New-Zealand	22
S. matsudana	SAMA	2.1	M	P	L (2.6)	L	S	N	N	1	China	23
S. matsudana	SAMA	1.8	M	P	L (2.7)	L	S	N	N	1	China	24
S. matsudana	SAMA	6.3	M	P	L (0.9)	L (0.2)	S	N	N	1	China	25
S. matsudana	SAMA	1.2-5.3 (T)	M	P	L (3.0)	-	S	N	N	1	China	26
S. miyabeana 'SX67'	SAMI	16.5-22.7	M	T	H	M (2.3)	O	Y	Y	2	Canada	27
S. miyabeana 'SX67'	SAMI	5.5-6.2	F, Y	P	M (5.5-6.2)	M (2.0)	O	N	N	2	Canada	28
S. miyabeana 'SX64'	SAMI	2.5-2.7 (T)	Y	P	L (0.4)	H (7.5)	-	N	Y	1	U.S.	29
S. miyabeana 'SX64'	SAMI	2.7-3.9	F	M	M (5.4)	M (1.3)	-	N	Y, N	2	U.S.	30
S. nigra	SANI	6.0-13.0	Y	P	L, M	M (2.6)	C	N	Y	2	U.S.	31

		(T)										
S. psammophila	SAPS	1.5 (T)	-	P	L (1.6)	-	S	N	N	1	China	32
S. psammophila	SAPS	1.4	-	P	L	L (0.2)	S	N	N	1	China	33
S. purpurea '9882-34'	SAPU	3.1-3.8	F	M	M (5.4)	M (1.3)	-	N	Y, N	2	U.S.	30
S. purpurea '9882-34'	SAPU	2.6 (T)	Y	P	L (0.4)	H (7.5)	-	N	Y	1	U.S.	29
S. sachalinensis 'SX61'	SASA	2.5 (T)	Y	P	L (0.4)	H (7.5)	-	N	Y	1	U.S.	29
S. sachalinensis x S. miyabeana '9870-40'	SSSM	3.2-4.2	F	M	M (5.4)	M (1.3)	-	N	Y, N	2	U.S.	30
S. sachalinensis x S. miyabeana '9870-23'	SSSM	2.7 (T)	Y	P	L (0.4)	H (7.5)	-	N	Y	1	U.S.	29
S. viminalis	SAVI	10.0	-	P	H (14.7)	M (1.79)	S	N	N	1	Switzerland	34
S. viminalis '1023' '1047' '1052' '1054'	SAVI	1.4-1.7	-	P	L (1.4-1.7)	-	C, S	N	N	2	Poland	35
S. viminalis 'Inger' 'Sven' 'Tordis' 'Torhild'	SAVI	1.9-7.6	Y	M	H	H (4.35)	O	Y, N	N	2	Ireland	36
S. viminalis	SAVI	1.5-2.9	F, Y	T	L, H	M (3.0)	O	Y, N	N	4	Ireland	37
S. viminalis '78-183'	SAVI	6.3-8.3	Y	M	H (11.0)	M (2.0)	C, S	Y	N	2	Sweden	38
S. viminalis 'Tora'	SAVI	2.2-7.5	F, Y	M	M, H (6.4-11.4)	M (2.0)	C	Y	Y	3	Sweden	39
S. viminalis 'Tora'	SAVI	2.3-8.3	Y	M	L, H (4.0-11.0)	M (2.0)	C, S	Y	N	4	Sweden	40
S. viminalis 'Bjorn' 'Tora' 'Jorr'	SAVI	2.7-5.7	F, Y	T	H	L	O	Y	N	2	Denmark	41
S. viminalis '77683' '77666'	SAVI	3.0	Y	M	L	-	S	N	N	1	Sweden	42
S. viminalis 'SQV 5027'	SAVI	6.0-6.3	F	M	M, H	H (14.1)	O	Y	N	2	Canada	43
S. viminalis	SAVI	2.6	Y	P	L (3.1)	M (2.0)	C	Y	N	1	Sweden	44
S. viminalis 'L78183' 'Loden' 'Jorr' 'Rapp' 'Tora'	SAVI	0.7-2.1 (T)	Y	P	L (2.6)	M (2.4)	C	N	N	1	Sweden	45

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S. viminalis	SAVI	2.9-3.0	Y	P	L (3.5)	M (2.0)	C	Y	N	1	Sweden	46
S. viminalis 'Jorr'	SAVI	2.0-19.5	F, Y	M	L, M, H (6.6-19.6)	H (4.4)	C, S	Y, N	N	9	U.K.	47
S. viminalis '77075' '77077' '77082' '77083' '77683' '82007'	SAVI	2.0-3.7	Y, M	P	L (2.5)	M, H (3.0-4.0)	C, S, O	Y	N	5	Sweden	48
S. viminalis	SAVI	1.6-2.3	-	P	L (1.9)	-	C	N	N	1	Sweden	49
S. viminalis 'Régalis'	SAVI	1.0-1.2	-	P	L (1.4-1.7)	-	S	N	Y, N	6	Germany	50
S. viminalis	SAVI	1.2 (T)	M	P	L (1.0)	-	-	N	Y	1	Belgium	51
S. viminalis 'Tora'	SAVI	1.3-1.5	Y, M	P	L (0.7-1.1)	M	C, S	N	N	1	Germany	52
S. viminalis 'Q683'	SAVI	1.8-3.4	1	M	H	H (20.4)	S	N	Y, N	2	U.K.	53
S. viminalis 'Jorunn'	SAVI	2.5 (T)	-	P	L (2.4)	L (1.0)	-	N	N	1	U.K.	54
Salix sp.	SASP	3.1	-	P	L	-	C	N	N	1	Sweden	55
Salix sp.	SASP	3.1 (T)	-	F	H	-	-	N	N	1	U.S.	56
Salix sp.	SASP	1.1-1.4	-	P	L (2.0)	-	-	N	N	1	Germany	57

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