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Journal Article

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Publication date:

2021-04

Permanent link:

<https://doi.org/10.3929/ethz-b-000455582>

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Originally published in:

Journal of Plant Ecology 14(2), <https://doi.org/10.1093/jpe/rtaa091>

Running title: Responses of *Bolboschoenus* to temperature and K

**The effect of temperature changes and K supply on the reproduction
and growth of *Bolboschoenus planiculmis***

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Abstract

Aims

Climate warming and agricultural non-point source pollution both resulting from anthropogenic activities have been projected to affect plant reproduction and growth in wetlands worldwide. In order to predict and mitigate impacts of these anthropogenic activities, it is important to investigate how marsh plants respond to such environmental changes.

Methods

In this study, *Bolboschoenus planiculmis*, a tuberous sedge with a wide distribution range in Eurasia, was selected to examine the effect of air temperature changes (15, 20 and 25 °C over 24 h; 20/10 and 30/15 °C, day/night) and K supply (0, 1, 3, 9 and 18 mM) on its reproductive and growth traits in climate chambers.

Important Findings

We found that high constant temperatures (20 and 25 °C) were more beneficial for tuberization of *B. planiculmis* than high alternating temperatures (30/15 °C), whereas aboveground biomass and shoot height were generally largest at high temperatures (30/15 and 25 °C). Both the reproductive and growth traits of *B. planiculmis* showed hump-shaped relationships with K supply, with an optimum around 1–3 mM K. The combination of high constant temperatures and optimal (1–3 mM) K concentrations promoted reproductive traits the most, whereas the combination of higher temperatures (30/15 and 25 °C) and K concentrations up to 9 mM increased growth traits only. We therefore conclude that population abundance of *B. planiculmis* might benefit from global warming and the additional K supply.

Keywords: Climate warming, non-point source pollution, functional traits, clonal

46 reproduction, wetland plants, marsh

47 **1. Introduction**

48 Anthropogenic factors, such as agricultural non-point source (NPS) pollution, have
49 affected plant reproduction and growth in wetlands worldwide (Kettenring *et al.*, 2011;
50 Hernández-Crespo *et al.*, 2016; Hayes *et al.*, 2017). Moreover, these effects have been
51 amplified by water losses following climate warming (Strack, 2008; Jeppesen *et al.*,
52 2010; Xu *et al.*, 2020). Although inland wetlands cover 6% of the world's land (Reis *et al.*,
53 2017), they provide many important ecosystem services, including water
54 purification, food source for migrating birds and habitat for plant and animal species
55 (Halls, 1997; Keddy, 2010; Junk *et al.*, 2013). As inland wetlands have no hydraulic
56 connection to the ocean (Wan *et al.*, 2003; Wang *et al.*, 2009), plant species in these
57 ecosystems are vulnerable to environmental change, especially those distributed in the
58 arid or semi-arid regions (Sun *et al.*, 2000). Therefore, a better understanding of the
59 effect of environmental change on the performance of wetland plants would allow to
60 predict, mitigate and adapt to the impact of future environmental changes on such
61 wetland ecosystems and help to protect and manage these vulnerable wetland
62 ecosystems.

63 Higher temperatures and lower diel temperature ranges (DTR) as projected for future
64 climate change are key factors influencing reproductive and growth traits of plant
65 species (Kummerow and Ellis, 1984; Stenström and Jónsdóttir, 1997; Stenström *et al.*,
66 2002). Reproductive traits such as bud growth and rhizome length, as well as growth
67 traits such as aboveground biomass and leaf dry weight generally increase with higher
68 temperatures (Gorham, 1974; Aleixo and Valio, 1976; Jónsdóttir *et al.*, 2005; Yang *et al.*,
69 2011). However, the temperature optima and limitations for these traits can vary to
70 a large extent, also in tuber-forming plants (Aleixo and Valio, 1976; Miles *et al.*, 1996).

For instance, bud growth of purple nutsedge (*Cyperus rotundus*) has its optimum at temperatures between 25 and 35 °C, whereas the optimal range for leaf growth is considerably higher (35–40 °C; Aleixo and Valio, 1976; Shamsi *et al.*, 1978). On the other hand, decreasing or eliminating DTR can inhibit tuber sprouting, shorten leaf longevity and reduce tuber biomass and shoot height (Bennett *et al.*, 1991; Travlos *et al.*, 2009). These impacts strongly depend on the species or the variety (Schütz, 1999; Wallace *et al.*, 2013). For example, seed germination of some *Carex* species such as *C. diandra* can improve under large DTR, while other *Carex* species such as *C. elongata* prefer constant temperatures (Schütz, 1999; Fernández-Pascual *et al.*, 2015). Hence, more studies need to be conducted to explore the effect of DTR on the reproductive and growth traits of tuber-forming plants.

Due to agricultural NPS pollution, nutrient concentrations such as nitrogen (N), phosphorus (P) and potassium (K) have increased in inland wetlands (Yan and Deng, 2002; Wang, 2014). While the effects of N and P on wetland plants have long been in the focus of research (e.g. Davis, 1991; Chiang *et al.*, 2000; Miao *et al.*, 2000; Wang *et al.*, 2008), no studies have assessed the impacts of increasing K concentrations on wetland plants so far. Moreover, K is reported to exert a greater influence than N and P on tuber yield or tuber expansion in plants such as Chinese water chestnut (*Eleocharis dulcis*) and lotus root (*Nelumbo nucifera*) (Zhou *et al.*, 1994; Chen and Pan, 2003; Liu *et al.*, 2008). This is the result of the direct positive effects of K on the translocation of photosynthates to tubers (Hartt, 1970; Haeder *et al.*, 1973; Armstrong, 1998). Thus, tuber plants generally perform well under high K concentrations (Wang *et al.*, 2015; Misgina *et al.*, 2016; Liu *et al.*, 2017). Additionally, K is essential for plant growth and increases plants' ability to overcome temperature stress, because of its role in maintaining enzyme stability and cell turgor (Sangakkara *et al.*, 1996; Mengel and

Kirkby, 2004; Hasanuzzaman *et al.*, 2018). Therefore, understanding the responses of plant growth to interacting effects of K supply and temperature regime can provide critical information on how wetland plants acclimate to the combination of over-fertilization due to agricultural NPS pollution and climate change effects, and thereby help to maintain the ecosystem functioning of inland wetlands.

The Western Songnen Plain is an important area developed inland wetlands. However, the marshes in this area have suffered from severe degradation due to increasing temperatures and intensive farming activities (Wang *et al.*, 2011; Chen *et al.*, 2018; Tian *et al.*, 2019). Increased K availability up to 0.7–2.0 mM due to surface irrigation with paddy water to might pose a threat to the growth of marsh plants in the Western Songnen Plain wetlands (Wang, 2014) besides saline-alkaline stress (Ying *et al.* 2018). *Bolboschoenus planiculmis*, one of the typical marsh plants in the Western Songnen Plain, is a herbaceous perennial helophyte in the sedge family, typically growing from tubers and found in marshes throughout Eurasia (Govaerts *et al.*, 2014). As the tubers of *B. planiculmis* are the major food source for a critically endangered bird species on the red-list, the Siberian white crane (*Grus leucogeranus*) (Bird Life International, 2018), the degradation of the marshes threatens the survival of Siberian white cranes. Although concern about the persistence of *B. planiculmis* marshes has increased, most studies have been focusing on ecophysiological response of *B. planiculmis* to soil saline-alkaline and water stress (Zhang *et al.*, 2014; Liu *et al.*, 2016; Liu *et al.*, 2018). It is therefore still unclear how *B. planiculmis* marshes respond to the interacting effects of higher temperatures and reduced DTR compared to the current temperature regime (Shen *et al.*, 2014), while nutrient supply increases due to surface irrigation with paddy water. Hence, in order to protect and restore the degraded marshes, it is crucial to assess the adaptation strategy of *B. planiculmis*.

Therefore, we studied the growth responses of *B. planiculmis* to interacting effects of DTR changes, mean air temperature and K supply in a climate chamber experiment to test the following four hypotheses:

(1) High mean temperatures are beneficial for the growth performance of *B. planiculmis*, but optimum temperatures of reproductive traits are lower than those for growth traits.

(2) A pronounced DTR at high temperatures is necessary for the growth of *B. planiculmis*.

(3) *B. planiculmis* grows well at higher K concentrations than it experiences under its original habitat conditions.

(4) K increases the ability of *B. planiculmis* to overcome low temperature stress.

2. Materials and methods

2.1. Field sampling area

We collected tubers of *Bolboschoenus planiculmis* in May 2015 from Momoge National Nature Reserve (MNNR) in the Western Songnen Plain (123°39' E, 45°55' N), Baicheng, Jilin province, China (Fig. 1). The vegetation is dominated by *Phragmites australis*, *B. planiculmis* and *Schoenoplectus nipponicus*. The typical soil types are salinized soil, solonetzic soil and meadow soil, with a background K concentration of 0.39 mM (Liu *et al.*, 2018).

The mean annual temperature of MNNR was 20.9 °C in 2017 and increased 0.28 °C/decade over the last 60 years (Fig. 2a), mainly due to an increase in mean minimum temperatures at a slightly higher rate, i.e. 0.31 °C/decade (Fig. 2d;). Changes in mean maximum temperatures were more variable, but also increased over time, albeit at a lower rate of 0.1 °C/decade (Fig. 2b). As a consequence, DTR decreased with 0.2 °C/decade during the growing seasons from 1951–2017 (Fig. 2c), reaching about

146 12 °C in 2017.

147 **2.2. Experimental design**

148 Tubers of similar size were selected and soaked in tap water to promote sprouting
149 prior to treatments. After three days, tubers with 1 or 2 shoots (2 to 5 cm high) were
150 selected and planted into pots (11 cm diameter and 18 cm high, three tubers per pot)
151 containing 8 cm of vermiculite at the bottom and 4 cm of prewashed quartz sand at the
152 top.

153 We placed the pots in five climate chambers with a 14-h light period at 1015 W/m²
154 and applied a fully crossed combination of five temperature levels and five K
155 concentrations. The temperature treatment consisted of two alternating temperatures
156 (day/night: 20/10 °C and 30/15 °C, with a mean of 15.8 °C and 23.8 °C, respectively)
157 and three constant temperatures (15 °C, 20 °C and 25 °C for 24 hours). Our two
158 alternating temperatures regimes (with 10 and 15 °C DTR) embrace the naturally
159 occurring DTR values well. The K concentration treatments included 0, 1, 3, 9 and 18
160 mM K, which were in the range of the background K concentration of our study area
161 (0.36 mM, Liu *et al.*, 2018), the surface irrigation with paddy water (0.7–2.0 mM,
162 Wang, 2014) and the optimum K of other tuber species such as lotus roots (13.5 mM,
163 Liu *et al.*, 2010) and sweet potato (20 mM, Liu *et al.*, 2017). This amounted to a total
164 of 75 pots (5 temperature treatments × 5 K concentration treatments × 3 replicates).

165 The shoots were watered every day to a water level of 2 to 3 cm above the quartz
166 sand surface with a modified Hoagland half-strength nutrient solution (see Liu *et al.*,
167 2018 for detailed information). In the treatment of 0 mM K concentration, 1.5 mM
168 NH₄NO₃ were added instead of 3 mM KNO₃ to keep the total N concentration the same
169 as the original Hoagland half-strength nutrient solution. Similarly, in the treatment of 1
170 mM K concentration, 1 mM KNO₃ and 1 mM NH₄NO₃ were added instead of 3 mM

KNO₃. In the treatment of 3, 9 and 18 mM K concentrations, 0, 6 and 15 mM KCl was added, respectively, besides 3 mM KNO₃. The nutrient solutions were renewed weekly. Mature leaves, tubers and aboveground parts were harvested for further analyses after four weeks.

2.3. Measurements

After the harvest, all plant samples were oven-dried at 70 °C to constant weight for at least 48 h and weighted. We recorded the number of new tubers that had formed by the end of the experiment (TN, per pot) and the total shoot number (SN, per pot), and measured the new tuber biomass (TB, g dry weight per pot), leaf dry weight (LDW, g per leaf), aboveground biomass (AB, g dry weight per pot) and shoot height (SH, cm). Leaf area (LA, cm² per leaf) of the third or fourth leaf from the bottom was measured before drying in order to calculate specific leaf weight (SLW, leaf dry weight/leaf area, g cm⁻²).

2.4. Statistical analyses

Interaction effects of temperature and K concentration on TN and SN were tested with generalized linear models (GLM, with quasi-Poisson distribution) using the function *glmer* from the R package *lme4* (Bates *et al.*, 2015). Similarly, interaction effects of temperature and K concentration on TB, AB, SH, LA and SLW were tested with linear mixed-effects models (LMM, *lmer*). Temperature and K concentration were considered as fixed effects, and the chamber as a random effect. In order to meet the assumptions of homoscedasticity, aboveground biomass was log-transformed. A Tukey *post-hoc* test was used for group-wise comparisons between the temperature and K concentration treatments. We normalized the values (Min–Max normalization) of these traits to depict the relative changes of the observed traits with temperatures and K concentrations. In order to detect long-term changes in diel temperature ranges in the

Western Songnen Plain, we obtained temperature data of the closest meteorological station in Baicheng (situated 70 km southwest of MNNR in Western Songnen Plain) from the China Meteorological Data Service Center (CMDC, <http://data.cma.cn>). Mean annual temperature (T_{Mean}), mean maximum temperature (T_{Max}), mean minimum temperature (T_{Min}) and diel temperature range (DTR, $T_{\text{Max}} - T_{\text{Min}}$) of the growing season (May to September) were calculated for 1951–2017. Temperature trends of T_{Mean} , T_{Max} , T_{Min} and DTR from 1951–2017 were analyzed with a linear model. All the statistics were conducted in R (R Development Core Team, 2017).

3. Results

3.1. Response of reproductive and growth traits to temperature

TN and TB significantly increased with higher temperatures from 15 °C to 25 °C, but were markedly lower at high alternating temperatures (30/15 °C; Fig. 3a–b, Tables 1, 2). In contrast, SN was the highest at the alternating temperature of 30/15 °C, whereas it remained persistently low at constant temperatures (Fig. 3c, Table 1). AB, SH and LA increased with higher temperatures across all the K concentration treatments irrespective of whether temperatures were constant or alternating (Fig. 4a–c, Table 2). SLW, on the other hand, was the lowest at 20 °C and showed a u-shaped relationship with temperature (Fig. 4d, Table 2).

3.2. Response of reproductive and growth traits to K concentration

The reproductive traits TN, TB and SN were highest in 1 and 3 mM K (Fig. 3d–e, Tables 1, 2). Also, the growth traits AB, SH, LA and SLW showed similar responses to K concentrations. All of them were the highest in 1 mM K concentration across all the temperature treatments (Fig. 4e–h, Tables 2). Very low K (0 mM) and very high K concentrations (18 mM) limited the growth of all reproductive and growth traits (Figs. 3d–e, 4e–h).

3.3. Interacting effects of temperature and K concentration on reproductive and growth traits

B. planiculmis showed higher reproductive and growth traits (except for SN and SLW) with increasing temperature, independently of K concentrations (Figs. 3a–c, 4a–d). However, only the combination of sufficiently high constant temperatures (20–25 °C) and optimum K concentrations (1–3 mM) promoted the growth of reproductive traits the most (Fig. 3d–f). For growth traits, higher temperatures (30/15 °C and 25 °C) helped *B. planiculmis* invest in higher AB, SH, LA and SLW under conditions with up to 9 mM K (Fig. 4e–h). In contrast, at low temperature (15 °C), only low K concentrations (1–3 mM) promoted growth traits (except for SH; Fig. 4e–h). However, at the low alternating temperature treatment (20/10 °C), low K concentrations (1–3 mM) had no beneficial effect on growth traits (except for SLW; Fig. 4e–h).

4. Discussion

The changes of temperature and K concentrations are key factors influencing species richness and ecosystem stability. Therefore, exploring their effects on the growth of *B. planiculmis* can provide the scientific base for restoration and management of *B. planiculmis* marshes under future climate conditions combined human activities.

Consistent with our first hypothesis, tuberization and aboveground biomass production of *B. planiculmis* increased with higher temperatures. This was different from the results observed in other species of the sedge family such as *E. dulcis*, *C. alrofusca* and *Kobresia humilis*, which showed decreased growth with higher temperatures (Chao *et al.*, 2000; Zhao *et al.*, 2006; Zhao *et al.*, 2007). A possible reason may be related to the fact that the optimum temperature for *B. planiculmis* might be higher than that of the other three sedge species. On the other hand, differing from our first hypothesis, the optimum temperatures of reproductive traits were not lower than

those for growth traits. This is not consistent with the findings observed in purple nutsedge conducted by Aleixo and Valio (1976) who found that the optimum temperatures were lower for bud growth (25–35 °C) than for aboveground growth (35–40 °C). This might be related to the fact that the maximum constant temperature (25 °C) in our study could be still lower than the optimum temperature for reproductive and growth traits, which is at date unknown. Hence, both, tuberization and aboveground biomass of *B. planiculmis* as well as reproductive traits increased with higher temperatures.

The formation of new shoots heavily relied on high alternating temperatures (30/15 °C), whereas aboveground biomass and shoot height generally increased with high temperatures, irrespective of whether it was constant or alternating temperatures (30/15 °C and 25 °C). This indicates that sprouting from tubers or rhizomes (leading to shoot formation) of *B. planiculmis* needs high alternating temperatures, similarly as observed in other species of the sedge family (Sun and Nishimoto, 1999; Kawabata and Nishimoto, 2003; Webster, 2003). This behavior might be related to the fact that alternating temperature is a major signal for dormancy release, in particular, since large temperature differences can shorten the dormant period (Miles *et al.*, 1996; Travlos *et al.*, 2009; Wallace *et al.*, 2013). Moreover, high temperature pulses were necessary to stimulate tuber sprouting in purple nutsedge (Kawabata and Nishimoto 2003), which could explain why new shoot formation at 20/10 °C was significantly lower than that at 30/15 °C (Figs. A1l, A1n). Surprisingly, under high alternating temperatures (30/15 °C) the tuberization of *B. planiculmis* was markedly lower compared to high constant temperatures (20 °C and 25 °C), which seemingly contradicts our second hypothesis. However, the allocation of resources to different plant parts underlies a fundamental trade-off (Craine, 2009, Bachofen *et al.*, 2019). Thus, the much lower number and

biomass of tubers in plants growing under high alternating temperatures can therefore be explained by the increased allocation of resources to shoot formation at the expense of tuber growth. Hence, although decreasing DTR probably promote the tuber reproduction due to inhibited shoot formation, the shoot density of *B. planiculmis* community might be inhibited under climate change conditions, as seen in the decrease of shoot formation with absent DTR at high temperatures.

The optimum K concentrations were 1–3 mM for tuberization and aboveground part growth of *B. planiculmis*, thus well within the range but with higher maximum K concentrations than those in the paddy water in Western Songnen Plain (0.7–2.0 mM, Wang, 2014). This supports our third hypothesis. Generally, tuber plants have a higher K requirement than non-tuber plants (Wang *et al.*, 2015; Misgina *et al.*, 2016; Liu *et al.*, 2017). For instance, the yield of lotus roots reaches its maximum even at 13.5 mM K supply (Liu *et al.*, 2010), while the growth of *Carex* is greatly inhibited at 3 mM or even 1 mM (Veerkamp and Kuiper, 1982). Therefore, irrigation with paddy water will not inhibit the growth of *B. planiculmis*, but rather promote its growth. However, excessive K concentrations (9–18 mM) limited both reproductive and growth traits of *B. planiculmis*, most likely due to an uptake imbalance with other important nutrients such as calcium (Ca) and magnesium (Mg) (Alva *et al.*, 2006; Marschner, 2011). In our study, we observed clear symptoms of Ca and Mg deficiency of *B. planiculmis* (data not shown), with only little root growth, dark-brown old roots and yellow-green leaves starting (from the third week on) at K concentrations of 9–18 mM (Kirkby and Pilbeam, 1984; Uchida, 2000; Cakmak and Yazici, 2010). Thus, if K supply further increases in paddy fields (Yang *et al.*, 2019), K concentrations might reach a detrimental level even for the K-tolerant plants, making it critical to adapt management strategies.

The optimum K concentrations combined with high temperatures exerted a positive

synergistic effect on the reproductive and growth traits of *B. planiculmis*. For growth traits, the range for high K concentrations tolerated *B. planiculmis* was wider at high temperatures (1–9 mM; 30/15 °C and 25 °C) than at low temperatures (1–3 mM; 15 °C and 20/10 °C). In contrast, optimum K supply did not have a significant positive effect at low temperatures, contradicting our fourth hypothesis. Low temperature severely inhibited the growth of *B. planiculmis* (Fig. 3), which might have constrained any positive effect of K supply. We suggest that high temperatures might promote the K tolerance of *B. planiculmis*, because higher temperatures increase enzyme activity and may thus relieve the toxic effect of high K concentrations, whereas lower temperatures decrease the enzyme activity and may lead to an exacerbated toxic reaction.

5. Conclusions

Our findings show that increasing temperatures and decreasing DTR increase tuberization and aboveground biomass production of *B. planiculmis*. Moreover, K supply from surface irrigation with paddy water might promote tuberization and aboveground growth of *B. planiculmis* in the Western Songnen Plain, when staying below 9 mM K. Additionally, higher temperatures increased the ability of *B. planiculmis* to overcome K limitation. Thus, global warming might increase the positive effect of agricultural NPS pollution (i. e. surface irrigation with paddy water) on the growth of *B. planiculmis* due to its higher K tolerance with increasing temperature.

Funding

This work was supported by National Key Research and Development Program of China (No. 2016YFC0500408), National Science and Technology Planning Project (No. 41771120), Chongqing Innovation Support Plan Fund for Returned Overseas Chinese Scholars (No. CX2019023), and a grant from State Key Laboratory of

Resources and Environmental Information System, An open project programme of the Key Laboratory of Geospatial Technology for the Middle and Lower Yellow River Regions (No. GTYR201906).

Acknowledgements

We thank Rong Mao for helpful suggestions on the manuscript and Shengda Yang, Zhijie Tian and Xueying Jia for their help with the field and laboratory work.

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Table 1 Generalized linear model results for the effects of temperature (T) and potassium concentration (K) on tuber number (TN) and total shoot number (SN) of *B. planiculmis*. DF: degrees of freedom, LR CHisq: Likelihood Ratio Chi square.

Variables	Factor	DF	LR Chisq	p-value
TN (per pot)	T	4	462.58	<0.001
	K	4	21.16	<0.001
	T:K	16	45.66	<0.001
SN (per pot)	T	4	1402.54	<0.001
	K	4	18.23	0.001
	T:K	16	55.36	<0.001

Table 2 Linear mixed model results for the effect of temperature (T) and potassium concentration (K) on tuber biomass (TB) and growth traits of *B. planiculmis*. AB: aboveground biomass; SH: shoot height; LA: leaf area; SLW: specific leaf weight. DF: degrees of freedom.

Variables	Factor	DF	Sum square	F value	p-value
TB (g dry weight pot ⁻¹)	T	4	1.32	91.68	<0.001
	K	4	0.49	34.15	<0.001
	T:K	16	0.29	4.99	<0.001
AB (g dry weight pot ⁻¹)	T	4	7.74	43.91	<0.001
	K	4	4.12	23.40	<0.001
	T:K	16	2.58	3.66	<0.001
SH (cm)	T	4	526.11	8.88	0.003
	K	4	863.75	14.57	<0.001
	T:K	16	848.45	3.58	<0.001
LA (cm ²)	T	4	25.05	10.56	<0.001
	K	4	57.90	24.41	<0.001
	T:K	16	22.60	2.38	0.010
SLW (g cm ⁻²)	T	4	1786.50	11.48	0.001
	K	4	4463.90	28.27	<0.001
	T:K	16	2285.50	4.15	<0.001

Fig. 1. Location of the tuber sampling plot of Momoge National Nature Reserve (MNNR) in the Western Songnen Plain. DEM: digital elevation model.

546 **Fig. 2.** Linear trends of a) mean annual temperature (T_{Mean}), b) mean maximum
 547 temperature (T_{Max}), c) diel temperature range (DTR) and d) mean minimum
 548 temperature (T_{Min}) for the period of 1951–2017 for Baicheng, Western Songnen Plain.
 549 Slope (S): change in temperature ($^{\circ}\text{C}/\text{decade}$); r^2 : regression coefficient; **: $p < 0.01$.

551 **Fig. 3.** Normalized value (± 1 s.e., $n=3$) of reproductive traits in response to
552 temperatures and K concentrations. 15.8 °C and 23.8 °C are the mean temperatures of
553 the DTR treatments 20/10 °C and 30/15 °C, respectively. TN: tuber number; TB: tuber
554 biomass; SN: total shoot number. See Appendix A for more specific details on the data
555 of reproductive traits in Fig. A1.

557 **Fig. 4.** Normalized value (± 1 s.e., $n=3$) of growth traits in response to temperatures and
 558 K concentrations. 15.8 °C and 23.8 °C are the mean temperatures of the DTR treatments
 559 20/10 °C and 30/15 °C, respectively. AB: aboveground biomass; SH: shoot height; LA:
 560 leaf area; SLW: specific leaf weight. See Appendix A for more specific details on the
 561 data of growth traits in Fig. A2.

562

Fig. 1. Location of the tuber sampling plot of Momoge National Nature Reserve (MNNR) in the Western Songnen Plain. DEM: digital elevation model.

209x297mm (300 x 300 DPI)

Fig. 2. Linear trends of a) mean annual temperature (T_{Mean}), b) mean maximum temperature (T_{Max}), c) diel temperature range (DTR) and d) mean minimum temperature (T_{Min}) for the period of 1951–2017 for Baicheng, Western Songnen Plain. Slope (S): change in temperature ($^{\circ}\text{C}/\text{decade}$); r^2 : regression coefficient; **: $p < 0.01$.

275x127mm (300 x 300 DPI)

Fig. 3. Normalized value (± 1 s.e., $n=3$) of reproductive traits in response to temperatures and K concentrations. 15.8 °C and 23.8 °C are the mean temperatures of the DTR treatments 20/10 °C and 30/15 °C, respectively. TN: tuber number; TB: tuber biomass; SN: total shoot number. See Appendix A for more specific details on the data of reproductive traits in Fig. A1.

131x153mm (300 x 300 DPI)

Fig. 4. Normalized value (± 1 s.e., $n=3$) of growth traits in response to temperatures and K concentrations. 15.8 °C and 23.8 °C are the mean temperatures of the DTR treatments 20/10 °C and 30/15 °C, respectively. AB: aboveground biomass; SH: shoot height; LA: leaf area; SLW: specific leaf weight. See Appendix A for more specific details on the data of growth traits in Fig. A2.

132x200mm (300 x 300 DPI)

Fig. A1 Clonal reproductive traits in response to temperatures and K concentrations. Means (± 1 s.e., $n=3$) with different lowercase letters are significantly different from each other ($p<0.01$). TN: tuber number; TB: tuber biomass; SN: total shoot number.

Fig. A2 Growth traits in response to temperatures and K concentrations. Means (± 1 s.e., $n=3$) with different lowercase letters are significantly different from each other ($p<0.01$). AB: aboveground biomass; SH: shoot height; LA: leaf area; SLW: specific leaf weight.

题目：温度变化和钾添加对扁秆藨草生长及繁殖的影响

摘要：

人类活动导致的气候变暖和农业面源污染已被认为影响湿地植物的生长和繁殖的重要因素。为了预测和缓解这些人类活动的影响，研究沼泽植物对这些环境变化的响应具有重要意义。本研究选取在欧亚大陆广泛分布的莎草科球茎植物扁秆藨草 (*Bolboschoenus planiculmis*) 为研究对象，研究气温变化（恒温：15、20、25 °C及交替温度：20/10 和 30/15 °C）和 K 添加（0、1、3、9 和 18 mM）对其生长和繁殖性状的影响。结果表明，高的恒温（20、25 °C）比高的交替温度（30/15 °C）更有利于扁秆藨草的球茎形成，而地上生物量和株高一般在较高温度下（30/15、25 °C）达到最大值。扁秆藨草的繁殖性状和生长性状均与施钾量呈驼峰型关系，最适施钾量在 1–3 mM K 左右。高恒温效应和最适（1–3 mM）K 浓度的交互作用对繁殖性状的促进作用最大，但是，较高的温度（30/15 和 25 °C）和 0–9 mM 的 K 浓度只促进了生长性状的生长。综上所述，扁秆藨草的种群优势度可能受益于全球变暖和额外的钾添加。

关键词：气候变暖，面源污染，功能性状，克隆繁殖，湿地植物，沼泽