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Growth Response of Rice and Paddy Weeds Under Elevated Temperatures

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This study was conducted to investigate the growth response of rice and annual paddy weeds under elevated temperatures. In the context of climate change, temperature is one of the most important climatic factors influencing the growth of crops as well as weeds. Rice and three major annual paddy weeds (*Monochoria vaginalis, Echinochloa crus–galli, and Ludwigia prostrata*) were grown under different temperature regimes (ambient, ambient+0.8°C, ambient+1.9°C, and ambient+3.4°C). Results revealed that the growth of rice and three annual paddy weed species increased with the temperature rise in the phytotrons. Above ground dry weight of rice was 1.31, 1.67, and 1.73 times higher at ambient+0.8, +1.9 and +3.4°C, respectively, than it was at ambient. Similar growth responses to rice was observed in *E. crus–galli* and *M. vaginalis* under the elevated temperatures. *L. prostrate* exhibited the most significant increases in leaf stage, leaf area, plant height, and plant dry weight, which were, respectively, 2.94, 3.57, 1.69 and 2.86 times higher at ambient+3.4°C than at ambient. Our findings suggest that climate change in the form of instant rising of temperatures might have an influence on the growth of rice and weeds and might confer relatively low competitive ability to rice.

Key words: Climate change, paddy weeds, rice, temperature

INTRODUCTION

The impacts of climate change are global concerns. The emission of greenhouse gases from agricultural systems is a main source of global temperature increase. Global warming is not uniformly experienced throughout the world. It is reported that the global temperature is predicted to warm by an average of 0.3°C to 4.8°C by the end of the 21st century with a likely increase of at least 1.5°C (IPCC 2013). Climate change has great potential to threaten the productivity and growth, as well as the production systems, of a wide range of crop species, especially those grown in open field systems (Rosenzweig *et al*., 2001).

In rice, extreme temperatures are of particular importance during flowering which usually lasts two to three weeks. Exposure to high temperatures for a few hours can dramatically reduce pollen viability and, subsequently, result in yield loss. Osada *et al*. (1973) and Matsui *et al*. (1997) reported that spikelet sterility was significantly increased at temperatures higher than 35°C.

Climate change not only influences the ecology of crops but also that of weeds. It is more likely for weeds than crops to show positive growth and reproductive responses when faced with changes in resources (water, nutrients, light, and CO_2) within climatic conditions due to their greater potential to adapt. Liu *et al*. (2008) found that temperature had a great influence on distribution, yield, and quality of soybean; their study demonstrated the great sensitivity of soybean to temperature change. Likewise, higher temperature levels also affect weed growth and development. Temperature is reported to affect strongly the geographical distribution of weeds (Patterson *et al*., 1979; Wolfe *et al*., 2008). It was reported that, with an increase of 3°C in temperature, the biomass and leaf area of itchgrass (*Rottboellia cochinchinensis*) increased by 88% and 68%, respectively (Patterson *et al*., 1979).

Weeds are one of the major causes of yield reduction in rice production everywhere in the world. It was found that weeds might be the reason for the annual rice yield reduction in sub–Saharan Africa by at least 2.2 million tons; equating to a US $ 1.45 billion loss (Rodenburg and Johnson 2009). Globally, yield losses due to pests and diseases have been estimated at approximately 40% of which weeds caused the highest loss (32%) (Rao *et al*., 2007). *Monochoria vaginalis, Echinochloa crus–galli,* and *Ludwigia prostrata* are the most important paddy weed species in rice cultivation in China, Japan and Korea. These weeds are of particular concern as they are the most dominant paddy weeds in Korea (Park *et al*., 2002; Won *et al*., 2015).

Many studies have shown that high temperatures can reduce grain yield (Ziska *et al*., 1996; Matsui *et al*., 1997; Horie *et al*., 2000; Prasad *et al*., 2006; Sung *et al*., 2014) owing to significantly increased spikelet sterility (Kim *et al*., 1996; Matsui *et al*., 1997; Jagadish *et al*., 2007; Ohe *et al*., 2007). However, limited numbers of

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studies have been conducted on the effect of elevated temperatures on rice and weed species. This study was undertaken to examine the response of rice and paddy weeds to elevated temperatures which may have a positive effect on their growth.

MATERIALS AND METHODS

Study Site

The experiment was conducted at the experimental farm in Chungnam National University, Daejeon, Korea (127°21′ E, 36°22′ N, alt. 34 m) in 2014. This area experiences the typical agro–climate of Korea where major crop fields are used for rice production. Annual mean precipitation was about 1,393 mm raining approximately 45% of the time (5.1 sunshine hours per day), from July to August (monsoon season) when most rice plants are in the reproductive phase. During the rice growing season, mean temperature is given as an average between May and October (21.8°C) whereas minimum and maximum are given between May and August (13.2°C and 30.8°C), respectively (Korea Meteorological Administration, 2014).

Field level phytotron for temperature manipulation

Four phytotrons were each built on a unit plot of 20 m×5 m by erecting semi–circular (tunnel–shape) steel frame on the ground and then covering it with a thin clear plastic sheet to elevate the inside temperature. A temperature control device was engineered using sensors to automatically open and close the ventilation of plastic windows to pre–calculated variable apertures to allow for exchange of air which maintained desired elevation of temperatures (ambient and, 0.8°C, 1.9°C, and 3.4°C above ambient level). Sensors in the phytotron measured temperature every 10 second and measured values were stored inside a cell phone system. Light intensity was similar across the phytotrons. A heater with a digital temperature sensor was installed in each phytotron, and the temperature was maintained at 0.8°C, 1.9°C, and 3.4°C above the ambient temperature during the experiment. One phytotron was maintained at ambient temperature as a control. Phytotrons were set to maintain temperatures at ambient, ambient +0.8°C, ambient+1.9°C, and ambient+3.4°C, simulating the temperature variation that could be observed with global climate change. The actual mean daily temperatures in the phytotrons for these temperature regimes were 21.4°C, 22.3°C, 23.2°C, and 24.5°C, which were 0°C, 0.9°C, 1.8°C, and 3.2°C, respectively, above ambient temperature (Fig. 1). The experiments were conducted in a randomized complete block design with four replications.

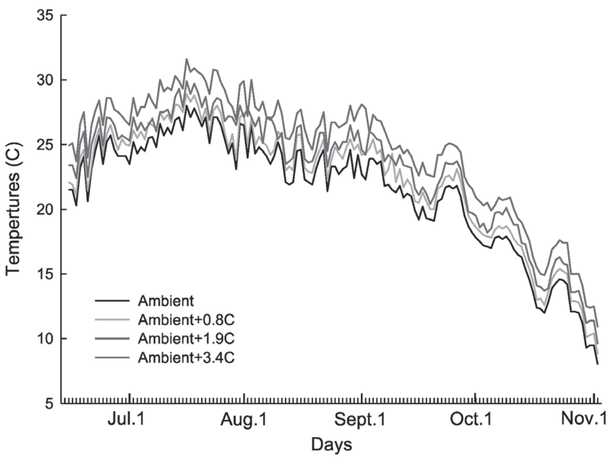

Fig. 1. Daily temperatures in the four phytotrons during the rice growing season.

Plant material

Seeds of one rice cultivar (Dongjin 1) and three annual paddy weeds *Echinochloa crus–galli, Monochoria vaginalis* and *Ludwigia prostrata*, previously harvested in the experimental field of the National Institute of Crop Science Korea in 2013, were sown at one seed per cell in plastic trays filled with upland rice field soil. Thirteen seedlings of each rice and weed species were transplanted at the 3–4–leaf stage into pre–puddled soils of phytotron on a 2 m × 6 m experimental plots with four replicates. The plots were arranged randomly with 50 cm space among each other. Each plant was arranged with 3 cm and 6 cm space for investigations 10 days and 20 days after transplanting, respectively. Chemical fertilizers (Namhae Chemical Corp., Korea) were applied at 210 kg N, 170 kg P, and 170 kg K ha^{-1} in the form of urea, diammonium phosphate, and sulphate of potash, respectively. All the fertilizers except urea were applied during final land preparation. Urea was applied in three splits (30% at 10 days after transplanting (DAT), 30% at 30 DAT, and 40% at panicle initiation stage). Black plastic film was applied on the surface of the plots to block emergence of any other weeds. After transplanting of rice and weed seedlings, water level was maintained at 2–3 cm on the surface of the plot. Leaf area and leaf stage were investigated 60 days after transplanting. Plant height and dry weight were investigated at 10 day intervals from 30 days to 120 days after transplanting. The leaf area was measured using a leaf area meter (LI–3100C, LI–COR, USA). For dry weight assessment, plants were gently pulled out from a plot and excessive soil was removed from roots by gentle rinsing with clean water. Plants were then softly wrapped with clean paper towels and placed in an electric oven drier at 72°C for three days prior to measuring the dry weight.

Statistical analysis

Data on plant height, dry weight, leaf numbers, and leaf area were subjected to one–way ANOVA using the SPSS software and means were compared by Duncan's Multiple Range Test. Non–linear regression analysis of accumulative dry weight was performed using log–logistic equations (Streibig., 1988; Seefeldt *et al*., 1995):

$$y = C + \frac{D - C}{1+\exp\{b[\log(x)-\log(H)]\}}$$

where y represents dry weight at growth rate x and C, D, b, and H are empirically derived constants. C is the lower limit, D the upper limit, b the slope at the H, and H the time required for 50% of growth.

RESULTS AND DISCUSSION

It was observed that all plants grew rapidly under elevated temperatures at 60 DAT while the growth rate of annual paddy weeds was higher than that of rice and the greatest increase in leaf stage, leaf area, plant height and dry weight were obtained at ambient+3.4°C (Table 1, Table 2). The total number of leaves of rice was 1.41 times higher at ambient+3.4°C than it was at ambient whereas the total numbers of leaves of *E. crus–galli, M. vaginalis*, and *L. prostrata* were, respectively, 1.63, 3.22, and 2.94 times higher at ambient+3.4°C than they were at ambient. Especially, *M. vaginalis* showed the highest increase in the total number of leaves at ambient +0.8°C, +1.9°C, and +3.4°C compared to those of other weed species and rice. Likewise, *L. prostrata* showed the second highest increase in the total number of leaves at ambient+0.8°C, +1.9°C, and +3.4°C as well (Table 1). Leaf areas of rice were 2.58 times higher at ambient +3.4°C than they were at ambient whereas those of *E. crus–galli* were 1.92 times higher than leaf areas at ambient, which was the smallest increase rate at ambient +3.4°C. Leaf areas of the other two weed species *M. vaginalis* and *L. prostrata* were, respectively, 3.55 and 3.57 times higher at ambient+3.4°C than they were at ambient. *L. prostrata* also showed the highest increase rates of leaf areas at all elevated temperature conditions (Table 2). Therefore, there was a strong positive relation between growth parameters observed at 60 DAT and temperature increase. Elevated temperature induced a distinctive increase in the total number of leaves and leaf areas of *M. vagina*lis and *L. prostrata* compared to those of rice.

Plant height and dry weight of rice and annual paddy weed species were investigated under elevated temperatures at 120 DAT (Table 3). Plant heights of rice were 1.28 times higher at ambient+3.4°C than they were at ambient while plant heights of *E. crus–galli*, *M. vaginalis*, and *L. prostrat*a were, respectively, 1.46, 1.78, and 1.69 times higher at ambient+3.4°C than they were at ambient. All weed species showed greater rates of plant height increase at ambient+0.8°C, +1.9°C, and +3.4°C compared to those of rice. *M. vaginalis* showed the highest increase rates of plant heights at all elevated temperature conditions (Table 3). A rapid increase of dry weight of rice and annual paddy weed species was detected under the elevated temperatures (Fig. 2). Based on the non–linear regression analysis of accumulative dry weight of rice and three annual weeds, the estimated maximum dry weight of rice at ambient +3.4°C was 1.73 times higher than at ambient while dry weights of *E. crus–galli*, *M. vaginalis*, and *L. prostrata* were, respectively, 1.71, 1.64, and 2.86 times higher at ambient +3.4°C than they were at ambient. *L. prostrata* showed the highest and second highest increase rates of dry weight at ambient+3.4 and +1.9°C, respectively (Fig. 2).

A previous study in Korea showed that *M. vaginalis* and *Scirpus juncoides* emerged 1 and 3 days faster, respectively, under temperature conditions elevated by 3°C, which also conferred advanced growth to these weed species (Park *et al*., 2010). Similarly, *Eleocharis kuroguwai* emerged 1–2 days earlier and reached the 5

Table 1. Leaf stage of rice and three paddy weed species under elevated temperatures at 60 days after transplanting

	Total number of leaves			
Plant Species	Ambient	Ambient+0.8°C	Ambient+1.9°C	Ambient+3.4°C
Oryza sativa	7.3±0.3 a	8.0±0.0 ab	8.8±0.3 b	10.3±0.8 c
Echinochloa crus–galli	6.0±0.0 a	7.0±0.0 ab	7.3±0.3 a	9.8±0.9 b
Monochoria vaginalis	62.5±3.3 a	87.5±2.7 b	131±9.4 c	201±12.0 d
Ludwigia prostrata	42.5±2.3 a	58.2±2.2 ab	76.9±5.5 b	125±16.1 c

Values with different letters within the same row differ significantly ($p<0.05$)

Table 2. Leaf areas of rice and three paddy weed species under elevated temperatures at 60 days after transplanting

	Leaf area (cm^2)			
Plant species	Ambient	Ambient+0.8°C	Ambient+1.9°C	Ambient+3.4°C
Oryza sativa	158±7.7 a	207± 6.1 a	272±19.2 b	408±34.1 c
Echinochloa crus–galli	295±6.6 a	325±5.9 a	383±18.0 a	567±58.4 b
Monochoria vaginalis	96.8±2.2 a	105± 1.2 a	181±10.1 b	344±36.2 c
Ludwigia prostrata	205±4.9 a	287±31.4 a	497±64.4 b	731±30.9 c

Values with different letters within the same row differ significantly ($p<0.05$)

Table 3. Plant height and dry weight of rice and three paddy weed species under elevated temperature conditions 120 days after transplanting

Species	Temperature	Plant height (cm)	Dry weight (g)
Oryza sativa	Ambient	81.3±5.41 a	33.2±2.09 a
	Ambient+0.8°C	90.5±2.50 ab	40.7±2.52 ab
	Ambient+1.9°C	97.1±1.09 bc	48.3±3.95 bc
	Ambient+3.4°C	103.8±2.29 c	53.1±1.92 c
Echinochloa crus–galli	Ambient	88.9±3.39 a	47.2±2.49 a
	Ambient+0.8°C	106.0±11.0 ab	58.9±2.02 b
	Ambient+1.9°C	121.2±5.54 bc	66.3±2.14 c
	Ambient+3.4°C	129.5±2.02 c	81.3±2.17 d
Monochoria vaginalis	Ambient	21.8±2.13 a	13.0±1.58 a
	Ambient+0.8°C	30.5±1.44 ab	14.7±2.19 a
	Ambient+1.9°C	34.9±2.70 bc	16.7±2.19 ab
	Ambient+3.4°C	38.9±2.26 c	22.5±2.18 b
Ludwigia prostrata	Ambient	99.3±2.78 a	23.8±0.44 a
	Ambient+0.8°C	118.5±4.25 b	26.0±0.58 a
	Ambient+1.9°C	156.7±2.67 c	57.0±3.51 b
	Ambient+3.4°C	167.8±3.30 d	66.3±2.85 c

Values with different letters within the same column differ significantly ($p<0.05$)

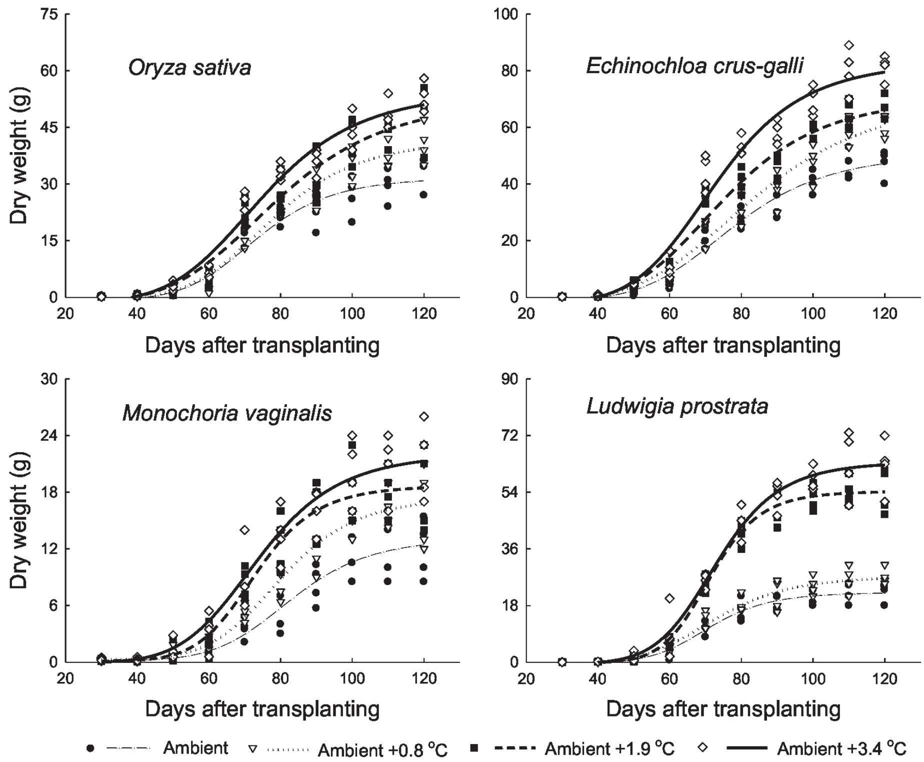

Fig. 2. Dry weight of rice and three annual paddy weeds grown under the elevated temperature regimes.

leaf stage 2–3 days earlier under temperature conditions elevated by 2°C (Kim *et al*., 2010). Furthermore, Kwon *et al*. (2013) analyzed factors related to the germination temperatures of 80 weed species in paddy fields of Korea and reported that positive effects of global warming on weeds, such as earlier germination and increased germination range, would decrease crop productivity by raising competition between weeds and crops. According to Kathiresan *et al*. (2016), climatic factors also affect the invasive traits of weeds and play a critical role in the establishment of weed species in different parts of the world.

Taken together in this study, elevated temperatures promote the growth of *M. vaginalis* and *L. prostrata* more than that of *E. crus–galli* and rice. *M. vaginalis* showed an increase in the total number of leaves and plant heights while *L. prostrata* showed increased leaf areas and dry weights under elevated temperatures. From the results of this study, we can conclude that rice and weed population responses would be altered under elevated temperature conditions. Rice yield would be affected by temperature increases, but weeds would remain an important yield–threatening factor. Therefore, the impact of climate change on crops and weeds will be an important issue for agricultural production and food security in Korea. Our study suggests that temperature could play an important role in the growth of rice and weeds in paddy fields, but further study is needed to examine yield potential under elevated temperatures.

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