Environmental Management (2012) 49:1238–1246
DOI 10.1007/s00267-012-9852-3

ENVIRONMENTAL ASSESSMENT

Responses of Two Invasive Plants Under Various Microclimate Conditions in the Seoul Metropolitan Region

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Received: 22 September 2011 / Accepted: 15 March 2012 / Published online: 7 April 2012

Abstract The possible consequences of global warming on plant communities and ecosystems have wide-ranging ramifications. We examined how environmental change affects plant growth as a function of the variations in the microclimate along an urban–suburban climate gradient for two allergy-inducing, invasive plants, *Humulus japonicus* and *Ambrosia artemisiifolia* var. *elatior*. The environmental factors and plant growth responses were measured at two urban sites (Gangbuk and Seongbuk) and two suburban sites (Goyang and Incheon) around Seoul, South Korea. The mean temperatures and CO_2 concentrations differed significantly between the urban (14.8 °C and 439 ppm CO_2) and suburban (13.0 °C and 427 ppm CO_2) sites. The soil moisture and nitrogen contents of the suburban sites were higher than those at the urban sites, especially for the Goyang site. The two invasive plants showed significantly higher biomasses and nitrogen contents at the two urban sites. We conducted experiments in a greenhouse to confirm the responses of the plants to increased temperatures, and we found consistently higher growth rates under conditions of higher temperatures. Because we controlled the other factors, the better performance of the two invasive plants appears to be primarily attributable to their responses to temperature. Our study demonstrates that even small temperature changes in the environment can confer significant competitive advantages to invasive species. As habitats become urbanized and warmer, these invasive plants should be able to displace native species, which will adversely affect people living in these areas.

Keywords Global warming · Invasive plants · Microclimate change · Urban environment · Plant response

Introduction

Global warming refers to the increase of the Earth's temperature due to increasing atmospheric concentrations of CO_2, N_2O, and CH_4 (and other greenhouse gases), a situation that enhances the greenhouse effect (Jung and Oh 1997), and the mechanism by which global warming influences ecosystems has become a major subject in climate research (IPCC 2007). To understand how climate change affects ecosystems over time, studies of the responses of plants to warming are required. Elevated CO_2 levels might affect ecosystems in multiple ways, such as causing physiological and ecological changes that alter species distributions (Bazzaz 1990). An earlier flowering period (Menzel 2000) under conditions of rising CO_2 levels, for example, may be advantageous to some members of plant communities (Fuhrer 2003), especially species that grow rapidly (Bazzaz 1990). Korea is a highly urbanized country that is experiencing one of the highest rates of temperature increase in the world, and the plant communities in Korea should accordingly show evidence of these effects (Ho and others 2006). Previous research has demonstrated that the temperatures in the Korean peninsula increased by approximately 2 °C from 1992 to 2004 (Ho and others 2006). Because Korea has a temperate climate, climate change affects many life history traits, including the flowering season and productivity (Lim and others 2006).

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Temperature rises are accentuated by urbanization because the surface heating rates in urban areas are higher than in rural areas during the growing season (Oh and others 2004). Global warming, in turn, accelerates the high temperatures of urban areas (Oh and others 2004), and urban areas have higher CO_2 levels (Grimmond and others 2002). The increased temperature and CO_2 conditions in urban areas (the heat island effect) fall within the scenario of future climate change according to the Intergovernmental Panel on Climate Change (IPCC) (Chung and others 2007). Therefore, the effects observed in current urbanization may be predictive of the future effects of global warming.

However, little research has been conducted on the responses of plants to climate change. Some studies have examined the effects of experimentally raised temperatures (Nijs and others 1996) and elevated CO_2 levels (Aranjuelo and others 2009). Although these types of studies are useful and essential for predicting the eco-physiological responses of plants in the future, the present tendencies cannot be revealed because the elevated conditions in these experiments are excessive. In contrast, field research focuses on the changes of the range limit of many plant species (Dyer 1994; Parolo and Rossi 2008) and the relationships between ecosystem change and climate change (Trivedi and others 2008). However, direct relationships between plant and climate changes have not been well studied in the field.

In Korea, the adaptability and vulnerability of vegetation to climate change (Jung and others 2003; Kong 2005), simulations of microclimate change (Jo and Ahn 2008) and flowering time (Ho and others 2006) have been studied. However, the relationship between climate warming and plant productivity (De Boeck and others 2007) and their responses, including the differences of plant productivity between urbanized and suburban areas by climate variation in Korea, have escaped the attention of international researchers. Because Korea has been subject to high levels of climate variation between the urbanized and suburban areas, measuring the plant responses along an urban-rural gradient, as affected on a small scale by variations in the microclimate, may provide insight into more general processes of global climate change.

As invasive plants may benefit more from a changing climate because they have the potential to respond to shifting niches more rapidly than native plants (Dukes and Mooney 1999), increasing temperatures in urban areas could be linked to an improved performance of invasive plants. Although the disturbance of the ecosystem has been known to be a major factor that impacts plant invasion, global warming and climate change have also been suggested as important factors. Climate changes, such as rising temperatures, can promote the growth of invasive plants and decrease the growth of native plants (Chapuis and others 2004). Consequently, the effect of global warming on ecosystems can result in the simultaneous increase in alien flora and a decrease in native flora (Pino and others 2005). Thus, studies on the performance of invasive plants in urbanized areas, such as Seoul, may allow us to predict future changes in the distribution of non-native plants.

In this study, we compared the performance of two invasive plants, the common ragweed (*Ambrosia artemisiifolia* var. *elatior*) and Japanese hop (*Humulus japonicus*), in urban and suburban areas. This study was prompted by research of the responses of *H. japonicus* and *A. artemisiifolia* var. *elatior* along urban (the Gangbuk and Seongbuk districts in Seoul) and suburban (the cities of Incheon and Goyang, adjacent to Seoul) environmental gradients, using microclimate variation as a proxy for climate change. We also conducted a greenhouse experiment to confirm the responses of the two plants to increased temperature.

Materials and Methods

Plant Species

H. japonicus S. et Z. is one of the major contributors to allergic symptoms in Korea. According to aerobiological studies in Korea, the *H. japonicus* pollen count is approximately 18 % of the total pollen count during the pollination period (Park and others 1999). *H. japonicus* is found widely in Korea (Oh and others 2008) and is one of the common invasive plants in the USA. (Kaufmann and Kaufmann 2007). Although many people suffer from *H. japonicus* pollinosis, only a few reports on this allergy have been published. *A. artemisiifolia* is also known to be a major allergenic plant and is the most common invasive plant in Korea. This plant is widely distributed in ruderal (disturbed) areas and in managed landscapes (Kil and others 2004), and the allergenic effects on humans have been long researched (Zwollo and others 1989). *A. artemisiifolia* is also known to be a noxious weed that inhibits the growth of other plant species (Brückner and others 2003), and it has been reported that it shows better performance in urban areas (Rogers and others 2006).

Research Sites

After a pre-survey in June 2009, four sites in the Seoul metropolitan region were selected for the field experiment. The pre-survey was conducted as follows. Landsat TM band 6 data from May 7, 2000, were used to analyze the land surface temperature (Kwon 2006). A geographical analysis was performed by comparing numerical maps at a 1:5,000 scale produced by the Korean National Geographic

Information Institute with the medium classification land-cover maps issued by the Korean Ministry of Environment in 2001. Based on these data analyses, we found two sites with high temperatures and CO_2 concentrations and two sites with the opposite conditions. The two high-temperature sites were urban areas (Gangbuk and Seongbuk), and the two low-temperature sites were suburban areas (Goyang and Incheon). The land use type of the two urbanized sites was classified as a traffic area, where plants were found in the narrow horticultural green spaces between roads. The land use type of Goyang was classified as farmland, and Incheon was classified as grassland; both areas were dominated by grassland with herbaceous plants. The geographic coordinates of the sites are as follows: Gangbuk (37°37′58.88″N and 127°00′26.14″E); Seongbuk (37°37′05.17″N and 127°03′27.16″E); Incheon (37°35′24.30″N and 127°37′22.30″E) and Goyang (37°37′47.47″N and 127°48′46.91″E). All four of the research sites are below 50 m above sea level.

Experimental Design

Areas in which *H. japonicus* and *A. artemisiifolia* var. *elatior* coexist were selected. A total of three quadrats (50 × 50 cm) for each species in open sites (no canopy coverage) were established in late April. Five random individuals were selected for height and biomass measurements, and the plant height was measured twice during the growing season. *H. japonicus* was harvested in July, immediately after flowering, as the biomass of these plants tends to decrease after flowering due to withering of the stem. *A. artemisiifolia* var. *elatior* was harvested in September for further analysis.

Soil and Plant Analysis

The soil was sampled within 5 cm of the surface in June. Four samples were pooled for further analysis. The soil was dried at 105 °C for 48 h to measure its water content. The soil organic matter (OM) content was determined by the loss on ignition (combustion at 550 °C for 4 h).

The total N, NH_4^+–N and NO_3^-–N analyses of the soil were performed using a Kjeldahl protein/nitrogen analyzer (Kjeltec Auto 1035 System; Tecator AB, Denmark).

The soil texture was determined using the hydrometer method (Sheldrick and Wang 1993). Forty grams of dry soil was mixed with 100 ml 5 % $(NaPO_3)_6$ and 300 ml distilled water and then shaken overnight. After shaking, the mixture was transferred to a 1,000 ml mass cylinder, and distilled water was added to bring the volume to 1 L.

The mass cylinder was covered with sealing film and shaken by hand thoroughly for one minute, and amyl alcohol was then added. The soil texture was determined using a soil hydrometer (ASTM 152H; Daegwang Measuring Instrument Factory, Korea) after 40 s (R_{40s}). After 7 h, we took a second measurement (R_{7h}). The contents of sand, clay and silt were calculated as follows:

$$\text{Sand }\% = 100 - (R_{40s} - R_L) \times \frac{100}{\text{oven-dried soil weight in grams}}$$

$$\text{Clay }\% = (R_{7h} - R_L) \times \frac{100}{\text{oven-dried soil weight in gram}}$$

$$\text{Silt }\% = 100 - (\text{sand }\% + \text{clay }\%),$$

R_L indicates the values of the soil hydrometer in 1 L of distilled water including 100 ml 5 % $(NaPO_3)_6$.

The plant samples were analyzed using an elemental analyzer (Flash EA 1112; Thermo Electron Co., USA) to determine the C and N contents.

Greenhouse Study

Plants of *H. japonicus* and *A. artemisiifolia* var. *elatior* were established in experimental pots in late June (six replicates each). The plants were grown in Sunshine Mix #5 (Sun Gro Horticulture, Canada). The germinated seeds were grown for 1 month in pots (14 cm upper diameter and 15 cm height) placed in growth chambers. Afterward, the pots ere moved into a greenhouse and an open field at Seoul National University. The plants were irrigated every day. The plants were harvested in late September, three months after transplanting.

Temperature and CO_2 Concentration

The temperature was monitored using a thermometer with a data logger (HOBO H9; Onset Computer, USA). The CO_2 concentration was measured between 1 and 3 pm in the afternoon at 30 cm above ground using an NDIR CO_2 analyzer (KRG7000; KORINS, Korea).

Statistical Analysis

The statistical significance ($P < 0.05$) of the differences was determined by one-way ANOVA, and Duncan's multiple range test was used for the post hoc comparison.

Results and Discussion

Environmental Factors

Figure 1A, B shows the mean temperatures and precipitation amounts at the four sites. The data from the closest weather station were provided directly by the Korea

Meteorological Administration. Between January and September, the average temperature in Gangbuk was 14.94 °C, 14.67 °C in Seongbuk, 13.60 °C in Incheon and 12.48 °C in Goyang. The differences between the urban (Gangbuk and Seongbuk) and suburban (Incheon and Goyang) sites were much greater than the global surface temperature increase (0.6 °C) of the past 100 years (Ho and others 2006). During the growing season (from March to July), the temperatures at the urban sites were 1.5 °C higher than at Incheon and 2 °C higher than at Goyang.

According to the statistical analysis of the mean daily temperature by month, Gangbuk and Seongbuk did not significantly differ, but both significantly differed from Incheon and Goyang (suburban areas) during almost every month. Only Incheon in January showed no significant difference compared with the urban areas. Overall, the temperatures of the selected urban and suburban areas showed significant differences.

The total precipitation of the four sites varied significantly (Gangbuk [1,368 mm], Seongbuk [1,307 mm], Incheon [1,267 mm] and Goyang [1,001 mm]). However, these differences were attributable to the different levels of precipitation during the rainy season and to heavy rainfall events (July and August), as other months showed no significant differences (Fig. 1B). Because the precipitation measurements in July and August were much higher than those in other months, Incheon and Goyang, which normally have low precipitation compared with the urban areas, did not suffer drought. Therefore, the differences in precipitation among the research sites do not appear to explain the differences in the plants' responses.

The CO_2 concentrations showed significant differences between the urban and suburban sites (Fig. 1C). The Seongbuk site, which is surrounded by residences and roads, showed the highest CO_2 concentrations.

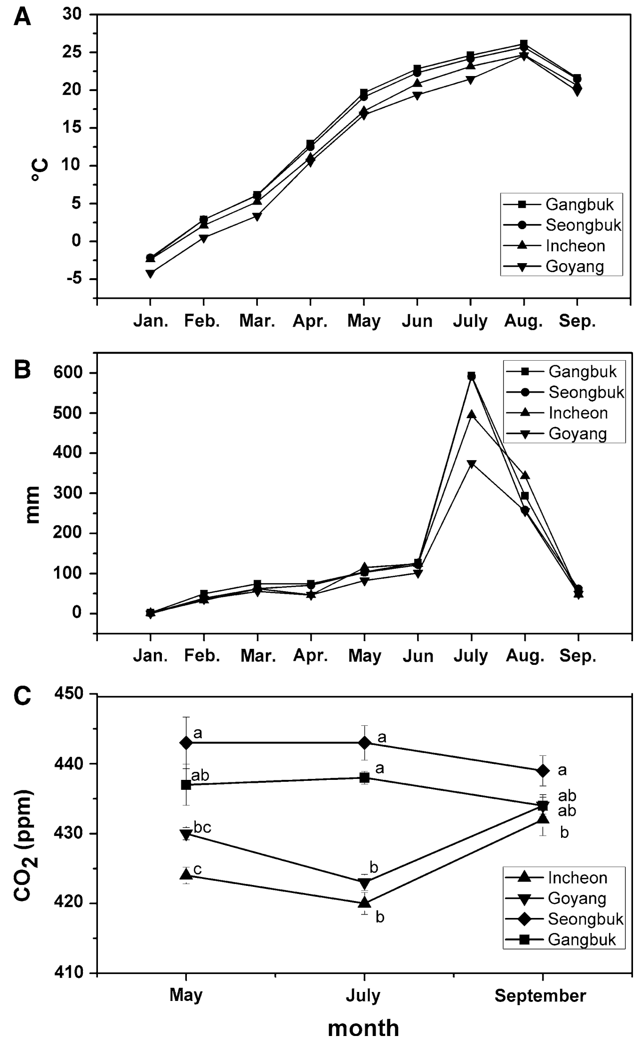

Fig. 1 Mean temperature, precipitation and CO_2 levels of the four study sites. **A** Monthly mean temperature, **B** monthly precipitation, **C** monthly CO_2 levels

Soil Characteristics

Table 1 shows the soil nutrients, OM content, moisture content and texture of the soil at the study sites. The soil nutrient content did not significantly differ among the four sites. However, the soil from Incheon showed a distinctively lower T–N (total nitrogen) content, and the soil from Goyang showed a distinctively higher NO_3–N content than the other areas. The soil from Goyang showed a significantly higher OM content and moisture compared with the other sites. The soil from Incheon showed higher contents of OM and moisture than the urban sites. The soil from Seongbuk and Gangbuk (urban sites) showed a significantly higher sand texture, indicating a low moisture holding capacity and less potential for retaining nutrients (Vereecken and others 1989). Overall, the soil conditions of the suburban sites appeared to be better than those of the urban sites, especially for the Goyang site. As the city green zones (gardening) of the urban areas are well managed, invasive plants, such as *H. japonicus* and *A. artemisiifolia*, tend to grow in rather unfavorable areas, such as roadsides and the barren, non-managed fields of the city. The soil conditions of these areas are usually poor, and the OM content of the urban areas cannot be increased because of the lack of litter decomposition due to frequent mowing (Kitchen and others 2009). Among the range of *H. japonicus*- and *A. artemisiifolia*-inhabited areas, the urban sites were not characterized by better soil conditions than the suburban sites.

Plant Responses in Fields

The height of *H. japonicus* in the urban areas did not show significantly greater values than in the suburban sites

Table 1 Soil properties of the four study sites

Items	Incheon	Goyang	Seongbuk	Gangbuk
T–N (%)	0.09 ± 0.02	0.15 ± 0.09	0.16 ± 0.04	0.18 ± 0.03
NH_4–N (mg/kg)	18.5 ± 4.87	20.5 ± 5.84	21.9 ± 0.40	12.8 ± 1.21
NO_3–N (mg/kg)	13.5 ± 1.21	42.9 ± 14.5	17.6 ± 1.39	18.7 ± 1.27
OM (%)	3.7 ± 0.7^{ab}	5.6 ± 1.5^{a}	2.2 ± 0.5^{b}	2.9 ± 0.2^{b}
Moisture (%)	12.4 ± 0.9^{ab}	27.4 ± 10.2^{a}	9.8 ± 0.94^{b}	16 ± 1.7^{ab}
Sand (%)	56.3 ± 6.9^{bc}	40.0 ± 5.9^{c}	71.3 ± 0.7^{ab}	77.9 ± 4.8^{a}
Silt (%)	19.2 ± 6.5^{ab}	32.1 ± 5.8^{a}	11.3 ± 0.7^{b}	14.0 ± 1.2^{b}
Clay (%)	24.6 ± 0.4^{ab}	27.9 ± 0.4^{a}	17.5 ± 0.7^{bc}	8.1 ± 0.6^{c}

The *data* are presented as the mean ± SE of three replicates

Means within a *row* followed by the *same letter* are not significantly different at the 0.05 level

Table 2 Plant height and biomass grown under field conditions in 2009

Items	Height (length:cm)				Biomass (g)	
Species	*H. japonicus*		*A. artemisiifolia*		*H. japonicus*	*A. artemisiifolia*
Month	May	July	July	Sept.	July	Sept.
Incheon	74.3 ± 11.3^{b}	360.0 ± 15.3^{a}	71.8 ± 1.2^{b}	107.4 ± 7.4^{b}	215.8 ± 14.8^{b}	301.2 ± 100.9^{c}
Goyang	58.5 ± 5.0^{b}	303.3 ± 14.5^{b}	79.8 ± 1.6^{b}	108.6 ± 4.1^{b}	384.7 ± 14.3^{a}	390.0 ± 56.0^{bc}
Sungbuk	101.9 ± 8.74^{a}	273.3 ± 3.3^{b}	102 ± 3.8^{a}	139.2 ± 2.1^{a}	365.3 ± 5.8^{a}	682.0 ± 73.3^{a}
Gangbuk	74.4 ± 9.54^{b}	260.0 ± 15.3^{b}	60.4 ± 5.9^{c}	130.2 ± 1.8^{a}	335.6 ± 4.2^{ab}	606.0 ± 52.3^{ab}

The *data* are presented as the mean ± SE of five replicates

Means within a *column* followed by the *same letter* are not significantly different at the 0.05 level

Fresh weights are given

(Table 2). However, because *H. japonicus* is a vine species whose plants have many stems, the length might not fully reflect the plant's performance; thus, biomass should be a better indicator of plant performance. The Goyang site showed the highest biomass of *H. japonicus*, and both of the urban sites exhibited significantly higher biomass than the Incheon site (Table 2). Because the soil of the Goyang site showed significantly higher organic matter, moisture and NO_3–N, the biomass of *H. japonicus* seems to reflect these soil conditions. However, even though the soil conditions of the urban sites (Gangbuk and Seongbuk sites) were poor, the biomass values of *H. japonicus* in the urban sites were only approximately 5–13 % lower than the Goyang site; although the soil conditions did not differ greatly, the biomass values of the urban sites were significantly higher (over 50 %) than those in Incheon.

As the canopy coverage of the research sites was the same (0 %) and the soil conditions were similar, the better performance (biomass) of *H. japonicus* in the urban sites could be partly explained by the climatic conditions. Because the growth of *H. japonicus* is so vigorous (Ju and others 2006) in fields, these tendencies are clear for *A. artemisiifolia* var. *elatior*, which showed significantly increased height at the urban sites compared with the suburban sites in September (Table 2). Indeed, the biomass values at the urban sites were nearly twice those in the suburban areas. Because *A. artemisiifolia* var. *elatior* is not a vine species like *H. japonicus* but grows upright, it is possible that environmental impacts might affect *A. artemisiifolia* var. *elatior* to a greater extent. However, the soil conditions of the urban areas were not better than those of the suburban areas, with other such environmental factors as canopy coverage, latitude and altitude being equivalent; thus, the microclimate gradient could be one of the reasons for these differences in biomass.

Global warming would extend the length of the potential growing season, allowing the earlier planting of crops (plants) in the spring (Olesen and Bindi 2002), and the responses of plants to rising atmospheric CO_2 concentrations often result in increased resource use efficiencies for radiation, water and nitrogen (Olesen and Bindi 2002). Overall, climate changes, such as warming and CO_2 increases, can increase the net primary production (Parton and others 2006). The differences in the climatic conditions can explain the differences between the urban and suburban areas. Because the precipitation between the sites did not differ (except in July and August) and because July and August are rainy seasons (the precipitation in July and August was more than twice that in the other months, and even the dryest site, Goyang, had sufficient precipitation),

Table 3 Chemical contents in the leaves of plants grown under field conditions

Species	*Humulus japonicus*		*Ambrosia artemisiifolia*	
Items	N (%)	C (%)	N (%)	C (%)
Incheon	3.42 ± 0.87	40.26 ± 0.46[ab]	2.74 ± 0.20[ab]	38.85 ± 0.22
Goyang	5.33 ± 0.51	40.97 ± 0.70[a]	1.89 ± 0.20[b]	41.49 ± 2.46
Sungbuk	4.26 ± 0.39	39.65 ± 0.32[ab]	3.25 ± 0.37[a]	40.07 ± 0.65
Gangbuk	4.32 ± 0.39	38.53 ± 0.99[b]	3.12 ± 0.13[a]	43.26 ± 0.81

The *data* are presented as the means and SE of three replicates

Means within a *column* followed by the *same letter* are not significantly different at the 0.05 level

rainfall was not a major factor that caused the observed differences in plant performance. Because a temperature increase of only 1 °C may be expected to increase plant productivity by approximately 10 % (Grace 1988), the increased temperatures of the urban areas in our study would be the major factor for the differences in performance. Elevated CO_2 concentrations could also be the main factor for these biomass increases. However, because most other studies have used CO_2 differences greater than 300 ppm, which is twice the ambient CO_2 level (Aranjuelo and others 2009; Erice and others 2007; Fuhrer 2003; Ro and others 2005; Rogers and others 2006), it is difficult to determine whether an increase of only approximately 20 ppm (approximately 5 %) (Fig. 1) would result in such changes. As even a 20 % CO_2 difference shows a less than 10 % biomass increase and a 100 % (over 300 ppm) difference shows a biomass increase in crop yields of only approximately 30 % (Olesen and Bindi 2002), our results, with differences of less than 5 %, would not be the major factor causing the greater than 50 % biomass increase at the urban sites. Although there is a possibility that the increased CO_2 significantly changed the plant performance in our experiment, the temperature differences would still be the major factor contributing to these differences.

The biomasses (g) of the reproductive organs (flowers) of *A. artemisiifolia* var. *elatior* were as follows: Seongbuk, 92.8 ± 12.2[a]; Gangbuk, 59.0 ± 6.8[b]; Goyang, 49.8 ± 12.7[b]; and Incheon, 45.0 ± 19.5[b] (The data are presented as the mean ± SE of five replicates. Means within a column followed by the same letter are not significantly different at the 0.05 level.). The flower mass but not the total biomass was greater at the urban sites. The reproductive organ/total biomass ratios were as follows: Incheon, 17.2 ± 4.0[a]; Seongbuk, 13.7 ± 0.79[ab]; Goyang, 12.5 ± 1.2[ab]; and Gangbuk, 9.8 ± 0.79[b] (The data are presented as the mean ± SE of five replicates. Means within a column followed by the same letter are not significantly different at the 0.05 level.). Thus, the urban sites did not show higher ratios than the suburban sites.

The chemical contents of the two invasive plants are shown in Table 3. Although *H. japonicus* did not show a significant difference in the leaf N contents, the urban sites showed greater N contents than the Incheon site. The high N content of the Goyang site represents good soil conditions (highest NO_3–N, OM and moisture). The N contents of the *A. artemisiifolia* var. *elatior* leaves at the urban sites were significantly higher than those at the suburban sites. Elevated temperatures and CO_2 concentrations can increase the N contents of plants (Room 1986; Erice and others 2007), but the relationship between increased temperature and N content has not been well studied. Furthermore, previous studies have shown that elevated temperatures and CO_2 concentrations do not always increase the N contents of plants (Room 1986; Erice and others 2007). However, the increased activity of plants that show better performance would be reflected in accelerated nutrient uptake. A simultaneous increase in the temperature and CO_2 would also increase the N content of plants (Ro and others 2005), as observed in the urban sites in the present experiment. Furthermore, because the N concentration of plants can be increased by motorway NOx (Saurer and others 2004), the values measured at the urban sites (classified as traffic areas) should increase, as was observed.

Overall, the two invasive, allergy-inducing plants (*A. artemisiifolia* var. *elatior* and *H. japonicus*) showed significantly higher biomasses and higher N contents in their leaves at the urban sites, even though the soil conditions of the urban sites were poorer than those of the suburban sites. The temperatures of the urban sites, which were 1.5 to 2 °C higher than those of the suburban areas, might explain the differences of the plant performance between the two sites. This hypothesis was verified by the greenhouse experiment, as described below.

Greenhouse Experiment

We conducted a greenhouse experiment to confirm the effects of the temperature increase on the two plant species. The mean temperature of the greenhouse was elevated by 3.8 °C compared with the open-field conditions (Fig. 2). The maximum temperature of the open field was 31.3 °C and,

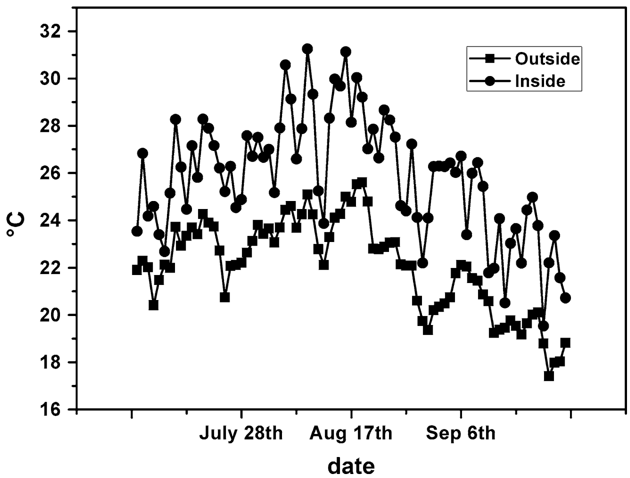

Fig. 2 Mean temperatures inside and outside of the greenhouse used in the study

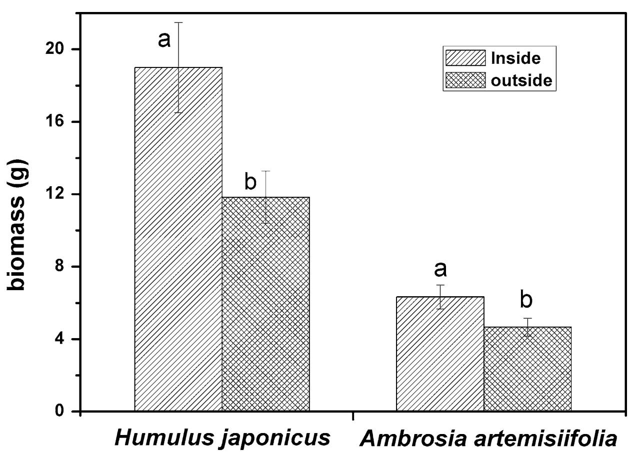

Fig. 3 Biomass of *Humulus japonicus* and *Ambrosia artemisiifolia* var. *elatior* inside and outside of the greenhouse used in the study; the *error bars* represent the mean ± SE of six replicates; *symbols* having the *same letter* are not significantly different at the 0.05 level

that of the greenhouse was 39.7 °C. The CO_2 concentrations of the greenhouse and open field were approximately 420 ppm, which were not significantly different.

Figure 3 shows that the biomasses of *H. japonicus* and *A. artemisiifolia* var. *elatior* were significantly higher under the greenhouse conditions. *H. japonicus* showed a greater than 50 % increase in biomass, indicating that the greenhouse offered better growing conditions for the two invasive plants. The N contents of *H. japonicus* showed a significant increase in the greenhouse (Table 4), whereas *A. artemisiifolia* var. *elatior* showed only a slight increase.

Because the other conditions (growth medium, irrigation, CO_2, canopy coverage and growing period) were the same, the higher greenhouse temperature most likely explains the observed differences. The increased biomass and nutrient concentration values indicate a high temperature adaptability of the two invasive plants. Because a 3.8 °C temperature increase induced these significant differences, the temperature differences between the urban and suburban sites would be sufficient to produce these effects under natural conditions. With the documented effects of such small temperature increases on plant growth and nutrient content (Grace 1988; Erice and others 2007), increased temperatures in urban areas might well affect plant performance.

Conclusions and Field Management Suggestions

Our results indicate that higher temperatures could improve the performance of invasive and noxious plants, allowing them to thrive in such urban areas as Seoul (Park and others 1999; Kil and others 2004; Rogers and others 2006). Therefore, these noxious plants should be carefully managed in urban areas. Because a few degrees of temperature increase resulted in better performance, the two invasive and allergy-inducing plants studied (*Ambrosia artemisiifolia* var. *elatior* and *Humulus japonicus*) might be able to exploit future temperature increases caused by regional and global warming, as indicated by the increased temperature and CO_2 conditions in the urban study sites, conditions that may be representative of future climate change (Chung and others 2007). Accordingly, these species are expected to continue their spread. Thus, appropriate management strategies for these noxious plants need to be developed.

As most urban areas would have landscape and horticultural management systems for green tracts of land, a scrupulous management system is required, with the education of field managers being the most important factor. *H. japonicus* and *A. artemisiifolia* are invasive species in

Table 4 Chemical contents in the leaves of plants grown under greenhouse conditions

Species	*H. japonicus*		*A. artemisiifolia*	
Items	Inside	Outside	Inside	Outside
N (%)	1.49 ± 0.14[a]	0.94 ± 0.02[b]	1.17 ± 0.06	1.03 ± 0.05
C (%)	41.54 ± 0.93	40.44 ± 0.49	38.95 ± 0.30	39.59 ± 0.70

The *data* are presented as the means and SE of three replicates

Means within a *row* followed by the *same letter* are not significantly different at the 0.05 level

Korea, but they should be controlled even in their native countries because they are strong allergy-inducing plants. Therefore, populated locales, such as urban areas, should have educated field managers who can develop management protocols for these plants. As *H. japonicus* pollinosis and *A. artemisiifolia* grow rapidly, the suitable season for removing (mowing, uprooting) these plants should be determined for each urban area.

Because *H. japonicus* grows rapidly and continues to germinate from the soil seed bank during the growing season (Lee 2010), uprooting seedlings in spring alone would not be effective. To prevent the production of seeds, the continuous mowing of *H. japonicus* until the complete consumption of the soil seed bank would be effective. In addition, because many *Asteraceae* species have similarly shaped leaves, plant identification skills are required for field managers. For example, *Ambrosia artemisiifolia* is similar to *Artemisia* species (*Artemisia montana* and *Artemisia lavandulaefolia*), which are considered edible and are used as traditional medicine in many countries (Lee and others 1992). *Ambrosia artemisiifolia* is also similar to some common horticultural species, such as orange cosmos (*Cosmos sulphureus*). During our research, the weeds of one site were completely mowed (the Seongbuk district in Seoul), but *Ambrosia artemisiifolia* survived because the managers confused this species with orange cosmos. Therefore, better education and management protocols are required. By recognizing that many noxious invasive plants could take advantage of the environmental conditions in urban areas (and future climate changes) and by developing educational and field management methods, we may have a better chance to prevent the spread of such allergy-inducing invasive plants.

Acknowledgments This study was funded by the National Institute of Environmental Research, Korea.

References

Aranjuelo I, Irigoyen JJ, Nogués S, Sánchez-Díaz M (2009) Elevated CO_2 and water-availability effect on gas exchange and nodule development in N_2-fixing alfalfa plants. Environmental and Experimental Botany 65:18–26

Bazzaz FA (1990) The response of natural ecosystems to the rising global CO_2 levels. Annual Review of Ecology, Evolution, and Systematics 21:167–196

Brückner DJ, Lepossa A, Herpai Z (2003) Inhibitory effect of ragweed (*Ambrosia artemisiifolia* L.)-inflorescence extract on the germination of *Amaranthus hypochondriacus* L. and growth of two soil algae. Chemosphere 51:515–519

Chapuis JL, Frenot Y, Lebouvier M (2004) Recovery of native plant communities after eradication of rabbits from the subantarctic Kerguelen Islands, and influence of climate change. Biological Conservation 117:167–179

Chung U, Lee KJ, Lee BW (2007) Preliminary report of observed urban–rural gradient of carbon dioxide concentration across Seoul, Suwan, and Icheon in South Korea. Korean Journal of Agricultural and Forest Meteorology 9:268–276

De Boeck HJ, Lemmens CMHM, Gielen B, Bossuyt H, Malchair S, Carnol M, Merckx R, Ceulemans R, Nijs I (2007) Combined effects of climate warming and plant diversity loss on above- and below-ground grassland productivity. Environmental and Experimental Botany 60:95–104

Dukes JS, Mooney HA (1999) Does global change increase the success of biological invaders? Trends in Ecology & Evolution 14:135–139

Dyer JM (1994) Land use pattern, forest migration, and global warming. Landscape Urban Planning 29:77–83

Erice G, Irigoyen JJ, Sánchez-Díaz M, Avice JC, Ourry A (2007) Effect of drought, elevated CO_2 and temperature on accumulation of N and vegetative storage proteins (VSP) in taproot of nodulated alfalfa before and after cutting. Plant Science 172:903–912

Fuhrer J (2003) Agroecosystem responses to combinations of elevated CO_2, ozone, and global climate change. Agriculture, Ecosystems & Environment 97:1–20

Grace J (1988) Temperature as a determinant of plant productivity. Symposia of the Society for Experimental Biology 42:91–107

Grimmond CSB, King TS, Cropley FD, Nowak DJ, Souch C (2002) Local-scale fluxes of carbon dioxide in urban environments: methodological challenges and results from Chicago. Environmental Pollution 116:243–254

Ho CH, Lee EJ, Lee I, Jeong SJ (2006) Earlier spring in Seoul, Korea. International Journal of Climatology 26:2117–2127

Intergovernmental Panel on Climate Change (IPCC) (2007) Fourth assessment report (AR4). Cambridge University Press, Cambridge

Jo HK, Ahn TW (2008) Differences in phenological phases of plants subsequent to microclimate change. Korean Journal of Environmental Ecology 22:221–229

Ju EJ, Kim JG, Lee YW, Lee BA, Kim H, Nam JM, Kang HJ (2006) Growth rate and nutrient content changes of *Humulus japonicus*. Journal of Ecology and Field Biology 29:433–440

Jung TY, Oh JK (1997) Global warming issue and Korean economy. The Hanyang Journal of Economic studies 18:229–242

Jung HC, Jeon SW, Lee DK, Matsuoka Y (2003) Evaluation of vegetation adaptability to climate change on the Korean peninsula using forest moving velocity. Journal of Korean Environmental Impact Access 12:383–393

Kaufmann SR, Kaufmann W (2007) Invasive plants: guide to identification and the impacts and control of common North American species. Stackpole Books, Mechanicsburg, p 458

Kil JH, Shim KC, Park SH, Koh KS, Suh MH, Ku YB, Suh SU, Oh HK, Kong HY (2004) Distributions of naturalized alien plants in South Korea. Weed Technology 18:1493–1495

Kitchen D, Blair J, Callaham M (2009) Annual fire and mowing alter biomass, depth distribution, and C and N content of roots and soil in tallgrass prairie. Plant and Soil 323:235–247

Kong WS (2005) Selection of vulnerable indicator plants by global warming. Asia-Pacific Journal of Atmospheric Sciences 41:263–273

Kwon YA (2006) Analysis of urban thermal environment properties using Landsat ETM+ in Seoul. Korean Journal of Urban Geography 9:147–157

Lee HHM (2010) Spatial variation of soil seed bank in downstream floodplains of the Han river. Doctorate thesis, Seoul National University, Seoul

Lee GD, Bae JO, Yoon HS, Kim JS (1992) Antioxidative effectiveness of water extract and ether extract in wormwood (*Artemisia montana* Pampan). Journal of the Korean Society of Food and Nutrition 21:17–22

Lim JH, Shin JH, Lee DK, Suh SJ (2006) Climate change impacts on forest ecosystems: research status and challenges in Korea. Korean Journal of Agricultural and Forest Meteorology 8: 199–207

Menzel A (2000) Trends in phenological phases in Europe between 1951 and 1996. International Journal of Biometeorology 44:76–81

Nijs I, Teughels H, Blum H, Hendrey G, Impens I (1996) Simulation of climate change with infrared heaters reduces the productivity of *Lolium perenne* L. in summer. Environmental and Experimental Botany 36:271–280

Oh SN, Kim YH, Hyun MS, Nam JC (2004) Impact of urbanization on climate change in Korea, 1973–2002. Asia-Pacific Journal of Atmospheric Sciences 40:725–740

Oh YJ, Yool JH, Moon BC, Sohn SI, Oh SM, Kim SC (2008) Habitat characteristic and community structures of *Humulus japonicus* in Korea's middle region. Korean Journal of Environmental Agriculture 27:72–79

Olesen JE, Bindi M (2002) Consequences of climate change for European agricultural productivity, land use and policy. European Journal of Agronomy 16:239–262

Park JW, Ko SH, Kim CW, Jeoung BJ, Hong CS (1999) Identification and characterization of the major allergen of the *Humulus japonicus* pollen. Clinical & Experimental Allergy 29:1080–1086

Parolo G, Rossi G (2008) Upward migration of vascular plants following a climate warming trend in the Alps. Basic Applied Ecology 9:100–107

Parton WJ, Scurlock JMO, Ojima DS, Schimel DS, Hall DO (2006) Impact of climate change on grassland production and soil carbon worldwide. Global Change Biology 1:13–22

Pino J, Font X, Carbó J, Jové M, Pallarès L (2005) Large-scale correlates of alien plant invasion in Catalonia (NE of Spain). Biological Conservation 122:339–350

Ro HM, Yun SI, Choi WJ (2005) Biomass production and N uptake of Chinese cabbages as affected by N rates under elevated atmospheric CO_2 and temperature. Journal of Korean Society of Horticultural Science 46:126–131

Rogers CA, Wayne PM, Macklin EA, Muilenberg ML, Wagner CJ, Epstein PR, Bazzaz FA (2006) Interaction of the onset of spring and elevated atmospheric CO_2 on ragweed (*Ambrosia artemisiifolia* L.) pollen production. Environmental Health Perspectives 114:865–869

Room PM (1986) Equations relating growth and uptake of nitrogen by *Salvinia molesta* to temperature and the availability of nitrogen. Aquatic Botany 24:43–59

Saurer M, Cherubini P, Ammann M, De Cinti B, Siegwolf R (2004) First detection of nitrogen from NOx in tree rings: a $^{15}N/^{14}N$ study near a motorway. Atmospheric Environment 38:2779–2787

Sheldrick BH, Wang C (1993) Particle size distribution. Soil sampling and methods of analysis. Lewis Publishers, Boca Raton, p 499

Trivedi MR, Morecroft MD, Berry PM, Dawson TP (2008) Potential effects of climate change on plant communities in three montane nature reserves in Scotland, UK. Biological Conservation 141: 1665–1675

Vereecken H, Maes J, Feyen J, Darius P (1989) Estimating the soil moisture retention characteristic from texture, bulk density, and carbon content. Soil Science 148:389–403

Zwollo P, Ansari AA, Marsh DG (1989) Association of class II DNA restriction fragments with responsiveness to *Ambrosia artemisiifolia* (short ragweed)-pollen allergen Amb a V in ragweed-allergic patients. Journal of Allergy Clinical Immunology 83:45–54