

Growth Rate and Nutrient Content Changes of *Humulus japonicus*

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ABSTRACT: The growth pattern and the seasonal changes in nutrient contents of *Humulus japonicus* were investigated. Stem length of *H. japonicus* reached the maximum from 240 to 260 Julian date and the median value was found at 255 Julian date. The maximum leaf area was observed from 235 to 248 Julian date and the median value was at 240 Julian date. The maximum growth rate of the stem length ranged from 205 to 227 Julian date. The leaf area showed the maximum growth rate from 196 to 214 Julian date. The median date in the growth rate of the stem length and leaf area was 212 and 205 Julian date, respectively. The growth rate of *H. japonicus* was related to rainy season and precipitation. Phosphorus and sodium contents of *H. japonicus* were correlated with maximum potential rate of relative growth. Although stem biomass of *H. japonicus* was 1.5~3.5 times larger than that of leaf, N content of the leaf (4.48~5.27%) was about 2 times higher than that of the stem (2.00~3.62%). High content of N might be responsible for the high growth rate of *H. japonicus* in summer. This result provides valuable information for appropriate timing for the removal of *H. japonicus*.

Key words: Growth pattern, *Humulus japonicus*, Maximum growth rate, Seasonal change of nutrient content

INTRODUCTION

Humulus japonicus S. et Z., Japanese hop grows rapid and spreads out as an annual vine with double and single hooked climbing hair (Ehara 1955). Its rapid growth causes serious problems at riverine wetland because *H. japonicus* covers neighboring plants such as *Phragmites communis* and *Miscanthus sacchariflous* in growing season and thus is an obstacle to the growth of the other plants (Seoul City 2001). This kind of plants which cause significant changes in structure and function of an ecosystem is named as invasive plants (Cronk and Fuller 1995).

There are four major options for dealing with invasive plants: prevention, early detection, eradication, and control. Although prevention is the first and the most cost-effective option, eradication is the preferred after the failure of the prevention. Eradication programs are mainly based on mechanical and chemical control and habitat management. Preferentially, the eradication program must evaluate its situation under the given circumstances to find the best methods and consider life history and physiological characteristics of species (Wittenberg and Cock 2001).

Nutrient stoichiometry of a plant has important physiological and ecological consequences (Medez and Staffankarlsson 2005). The leaf C/N ratio influences photosynthetic rate (Field and Mooney

1986) and the C/P ratio is related to the maximum potential relative growth rate (Thompson et al. 1997). Nutrient stoichiometry in general and C/N ratio in particular determines the quality of plant tissue as food for herbivores (Ohlson and Staaland 2001, Mattson 1980, Haukioja et al. 1991). Tissue nutrient contents are also helpful to identify the ecological strategies of resource consumption and to predict the result of plant competitive interactions (Tilman 1982). The pivotal role of mineral nutrients in the biology of individual plant species has become increasingly obvious (Thompson et al. 1997, Lambers and Poorter 1992, Reich et al. 1992). The composition of mineral elements in plants has seasonal changes and can be associated with the development stage (e.g. shoot extension) and mobilization of minerals (Marrs 1978).

Studies on the growth pattern of *H. japonicus* and its effects on the wetland ecosystem has been insufficient until now except for the information on the morphological characteristics (Ehara 1955) and the chemical components of the leaves and stems harvested in September (Hur et al. 2003). For reasonable management of *H. japonicus*, we need to investigate the growth pattern of *H. japonicus* and its effects on nutrient cycling of wetland ecosystems through seasonal change of chemical components.

The purposes of this study were to present the growth pattern of *H. japonicus* and the seasonal changes of nutrients in the stems and leaves for deciding appropriate timing for the removal of *H. japonicus*.

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MATERIALS AND METHODS

The study areas were Amsa-dong ecological preservation area (N 37° 32', E 127° 07"), Tan stream ecological preservation area (N 37° 28', E 127° 07') and Osan stream (N 37° 05', E 127° 02'). Amsa-dong ecological preservation area naturally formed with sediments along the Han River and was dominated by *Phragmites communis*, *Miscanthus sacchariflous* and *Salix koreensis*. *Humulus japonicus*' coverage increases occasionally to 40% and species diversity decreases in the communities. Tan stream is also a tributary of Han-river in which coverage of *H. japonicus* was 31.4% and those of *P. communis* and *M. sacchariflous* were 4.7% and 3.2%, respectively (Seoul City 2001). Osan stream proceeds from Giheung reservoir and flows through Osan city. Because there are some agricultural areas, factories and residences along the stream, ecosystems have been disturbed and the coverage of *H. japonicus* was 20.4% (Ministry of Construction and Transportation 2001). River bank was reconstructed for improvement of ecological function and ecosystem structure from 2002 to 2006. These sites were very similar environmental characteristics in respects of climate and latitude (Seoul City 2001).

In 2004, we investigated in 5 sites for repetition; 2 sites in Amsa-dong, 2 sites in Tan stream and 1 site in Osan stream. We harvested *H. japonicus* and measured the stem length and leaf area of 25 individuals in each site with ruler in the field. The investigations were accomplished twice a month from July to October.

In 2005, we did not measure directly the stem length and leaf area in the field but estimated with dry weight. So, *H. japonicus* was collected twice a month from May to September at only one site in Amsa-dong. We harvested randomly twenty-five individuals of *H. japonicus* at five points and transported to the laboratory. Collected plants were separated into stem and leaf. Fresh leaves and stem were dried to constant weight at 80°C and weighed.

However, we measured directly stem length of above 125 individuals sampled from May to July with ruler to earn data for estimation before drying. We found a function of the ratio of stem length to dry weight with time and then estimated the stem length with dry weight and the ratio. We also measured directly the area of 50 leaves sampled in July with LI 3100. Then, we found the relation of leaf area with dry weight and estimated leaves area with dry weight of leaves.

For analysis of nutrients, dried leaves and stems of 5 plants were finely milled once a month from April to August. Ground samples were digested in Nitrate with a Microwave (CEM MARS, Xpress, USA, 2004) and were analyzed with an Atomic Absorption Spectrophotometer (AA240FS, Varian, USA, 2004). The digested acid was naturalized with sodium hydroxide and analyzed for P with

acetic acid method (Kwon 2006). Nitrogen, carbon and hydrogen were analyzed with Elemental Analyzer in National center for inter-university research facilities, Seoul National University.

RESULTS AND DISCUSSION

Estimation of Stem Length and Leaf Area from Dry Weight

We estimated the stem length and leaf area of *H. japonicus* from dry weight after August. Estimation is more economic and accurate than direct measurement because high temperature in August can make harvested plants wilt in a short time. In addition, growth of *H. japonicus* was so vigorous that too much time and effort were required for direct measurement of stem length and leaf area. We found a relation of stem length and leaf area with dry weight from the measured data.

The ratio of dry weight to stem length tends to decrease with time (Fig. 1). This relation can be expressed as below exponential function.

Stem length = $W_s * 1118.8708 * e^{(-0.0158*d)}$ where W_s means dry weight (g) of stem and d means Julian date.

The leaf area of *H. japonicus* was directly proportional to dry weight (Fig. 2) and regression equation was below.

Leaf area (cm^2) = $304.6439 * W_l$ where W_l means dry weight (g) of leaves.

Stem length and leaf area were estimated from above functions when these were not directly measured.

Growth Pattern

The dry weight of stem and leaf of *H. japonicus* at Amsa-dong in 2005 is presented in Fig. 3. Plant growth was expressed with biomass at first. Also, we translated biomass into stem length and leaf

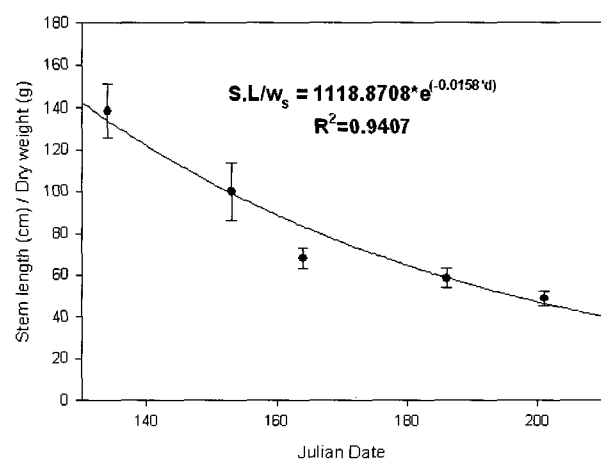


Fig. 1. Exponential decrease of ratio of stem length (S.L.) and dry weight (W_s) with time (d).

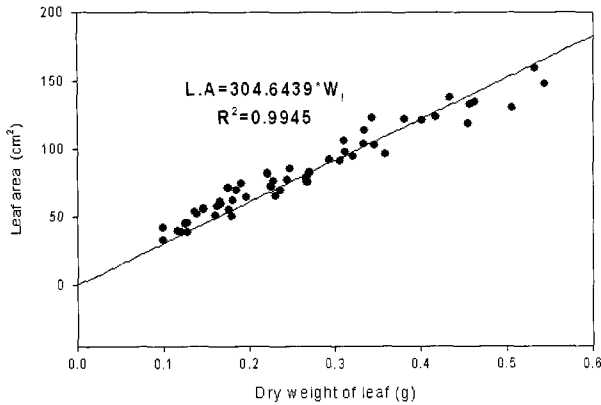


Fig. 2. Relation between leaf area (L.A.) and dry weight (WI).

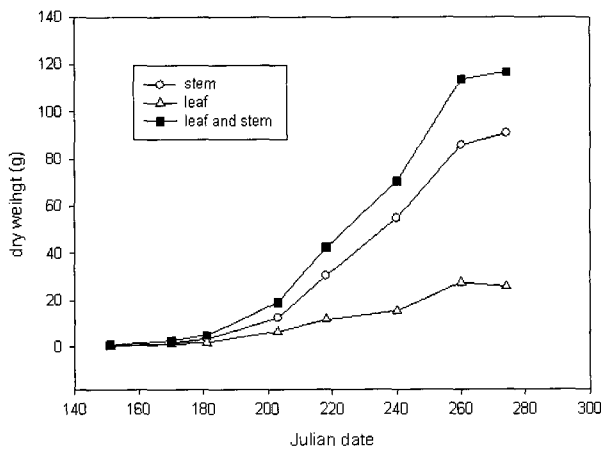


Fig. 3. The change of leaf and stem biomass with time at Amsa-dong in 2005

area by using above functions to see how further *H. japonicus* extends in short period.

The maximum total leaf area and stem length of a plant was 5,779 cm² and 2,049 cm in August 30 (Figs. 4 and 5). Leaf area and stem length of *H. japonicus* increased exponentially and plant growth was expressed as exponential function in general (Hurt 1982). However, the cubic equation is much better to search maximum growth rate of leaf area and stem length (Chang and Yoshida 1973). Fitted cubic equations of the leaf area and stem length of *H. japonicus* at Amsa-dong in 2005 are following.

$$F_s(t) = 34401.0048 - 542.9159t + 2.7566t^2 - 0.0044t^3$$

$$F_l(t) = 129183.0126 - 2051.4856t + 10.5002t^2 - 0.0171t^3$$

where 'l' means leaf area and 's' means stem length. The functions differentiated by t are

$$F_s(t)/dt = -542.9159 + 5.5132t - 0.0132t^2$$

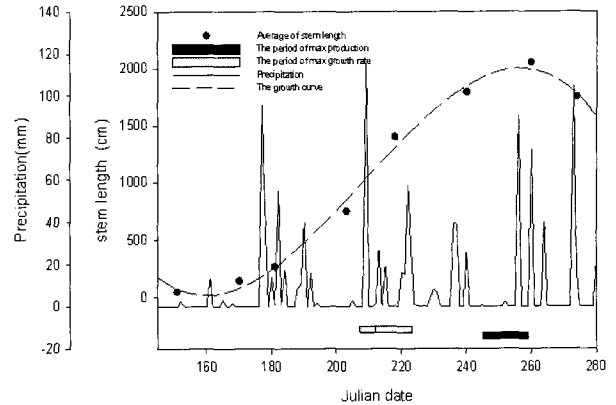


Fig. 4. The change of stem length with time and precipitation in 2005.

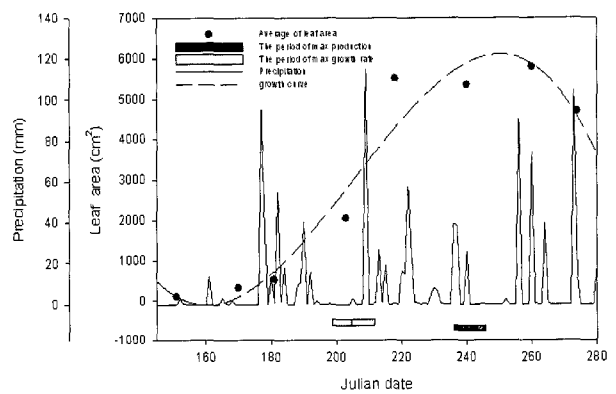


Fig. 5. The change of leaf area with time and precipitation in 2005.

$$F_l(t)/dt = -2051.4856 + 21.0004t - 0.0513t^2$$

The time of maximum value of $F(t)/dt$ expresses the time of maximum growth rate. Maximum growth rate of stem and leaf of *H. japonicus* at Amsa-dong were observed at 209 and 204 Julian date, respectively. The time of maximum plant stem length and leaf area were 259 and 248 Julian date, respectively. Then stem length and leaf area of *H. japonicus* decreased gradually with the death of some part of *H. japonicus*.

When we analyzed the data of 5 sites in 2004 in this way, the results were little bit different among study sites. The period that showed maximum stem length was from 240 to 260 Julian date and the median value was 255 Julian date in 2004. Maximum leaf area was observed from 235 to 248 Julian date and the median value was 240 Julian date. The maximum growth rates of stem length and leaf area were showed from 205 to 227 and from 196 to 214 Julian date, respectively and the median date was 212 and 205, respectively.

The growth rate of *H. japonicus* tended to coincide with the period of rainy season. In 2005, the rainy season was from 178 to

199 Julian date. The growth rate gradually increased during rainy season. At several days after rainy season, the growth rate arrived at the maximum value. Then the growth rate of stem length and leaf area gradually decreased. Therefore, the amount of precipitation is likely to affect the growth of *H. japonicus*.

The Change of the Element with Growth of *H. japonicus*

Carbon contents in *H. japonicus* increased to 35% until 181 Julian date and then remained. Hydrogen content was not changed obviously and sustained at about 4.5~5.5%. Both of C and H contents were not correlated with growth rate.

Phosphorus content in leaves tended to increase to 0.22% at 181 Julian date and then decreased. These values were much higher than 0.053~0.14% reported by Hur et al. (2003). The highest P content in stem was observed at the time of maximum growth rate even though that in leaf was observed a little bit earlier than the time of maximum growth rate. Total P content closely coincided with growth rate because stem had about 1.5~3.5 times more dry weight (Fig. 7). Content of P was positively correlated with maximum potential relative growth rate (Thompson et al. 1997).

Na content of *H. japonicus* was also related with growth rate (Fig. 6). The lowest Na contents of leaves and stem were 0.005% in June and 0.0062% in July, respectively. In contrary to P content, Na content was low in the period of maximum growth rate. Na content of stem exactly corresponded to the value of growth rate but leaf did not. This can be explained like P by total content.

It was reported that N and P contents were strongly and negatively correlated with each other (Ågren 2004, Thompson et al. 1997). This was due to a "dilution" in N content with increasing size that has been reported for some plants (Lutze and Gifford 1998, Ohnmeiss and Baldwin 1994) and increasing tendency in P content with plant growth. In this study, N dilution was little observed; N content was constantly high for the whole growth period. Only Mg content decreased as plants grew and showed a dilution tendency obviously in both of leaf and stem. In April, the value was 0.42% in leaf and stem. Those values constantly decreased with time and arrived at 0.20% and 0.14 in August.

Seasonal Biomass and Nutrient Allocation

In our investigation of *H. japonicus*, total biomass of stem was 1.5~3.5 times larger than that of leaf (Fig. 7). Dry weight ratio of stem and leaf tended to gradually increase. That is explained that energy allocation of *H. japonicus* is attached importantly to stem. *H. japonicus* can grow extensively and an individual grows maximum 21m (our observation).

Nutrient and biomass allocation patterns are known to be different from species to species (van Andel and Vera 1977). The

allocation pattern of plants are the fundamental aspect of their life history strategies (Kawano and Nagai 1975). Biomass has frequently been used in resource allocation studies to indicate energy allocation patterns because biomass and energy content have been shown to be generally equivalent (Hickman and Pitelka 1975). Biomass and total carbon ratios of stem and leaf were continuously increasing. Energy content in stem is stronger than leaves (Figs. 7 and 8). Because the plant is annual and ruderal vine, one of the survival strategies is quick elongation of stem. That strategy gives the plant more light and area for photosynthesis. That phenomenon is likely to be due to competition with inter- or intra species.

Leaf nitrogen content and photosynthetic capacity are highly correlated (Kull and Jarvis 1995, Reich et al. 1998). This correlation is due to the limitations on photosynthetic capacity imposed by the levels of photosynthetic enzymes (James et al. 1980). Especially N content of *H. japonicus* leaf was 4.48~5.27%. It was about 2 times of stem (2.00~3.62%) or more (Fig. 6), which can increase photosynthetic activity. However, total amount of nitrogen was not significantly different between stem and leaf because of the difference in total dry weight. K was another element showing difference between leaf and stem but K content of stem was higher than of leaf.

CONCLUSION

1. The periods of maximum productivity in stem and leaf were from 240 to 260 and from 235 to 248 Julian date, respectively. The maximum growth rates of stem length and leaf area were showed from 205 to 227 and from 196 to 214 Julian date, respectively. We suggest removing *H. japonicus* before this period because handling the plant is completely simple.
2. P and Na contents of *H. japonicus* were strongly correlated with growth rate positively and negatively, respectively. Most of nutrients in *H. japonicus* were correlated with growth rate and each other (K, Mg, H). However, only Mg and N showed the tendency of dilution with plant growth.
3. *Humulus japonicus* allocated more C (the energy) to stem than leaf. That was the strategy for survival to get more light and larger habitat. N content of leaf was about 2 times of stem or more, which can increase photosynthetic activity.

ACKNOWLEDGEMENT

This work was supported by Korean Ministry of Environment as "The Eco-technopia 21 project" titled in "Evaluation of ecological impacts of invasive vine-plants on biodiversity and ecological function in riverine ecosystems and development of management strategy" and by the Brain Korea 21 Project of Seoul National University in 2006.

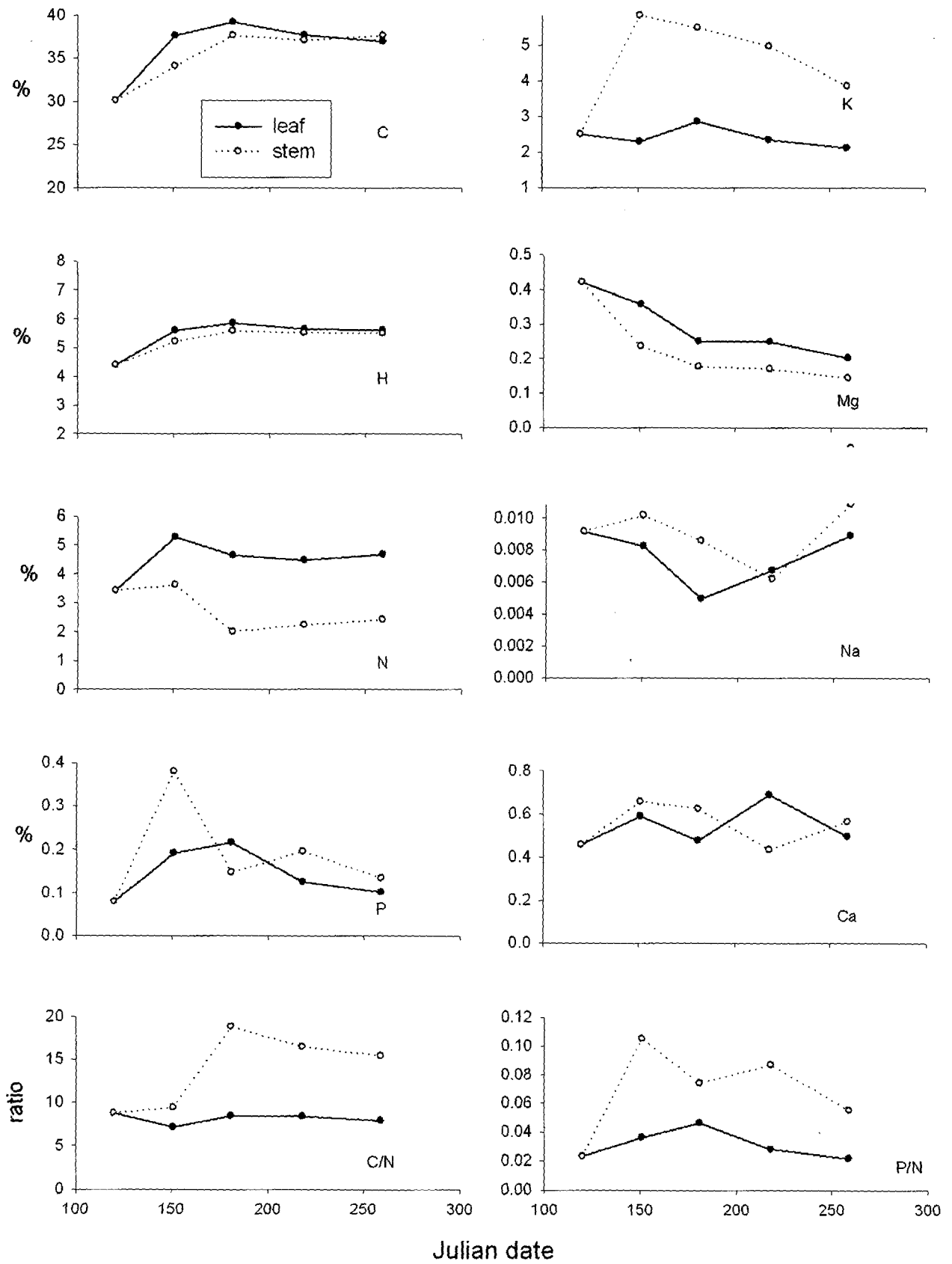


Fig. 6. The change of nutrient contents in *H. japonicus* with time.

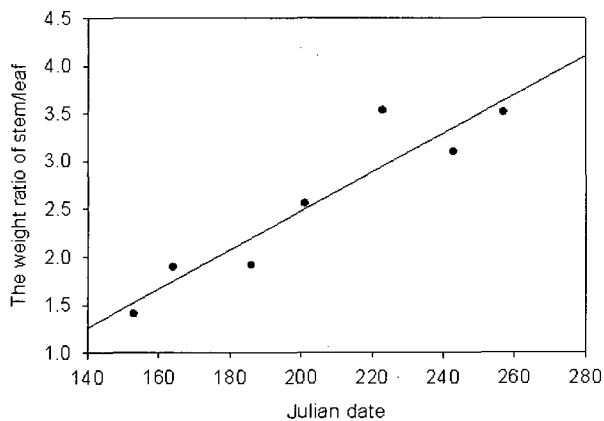


Fig. 7. Biomass allocation of stem and leaf.

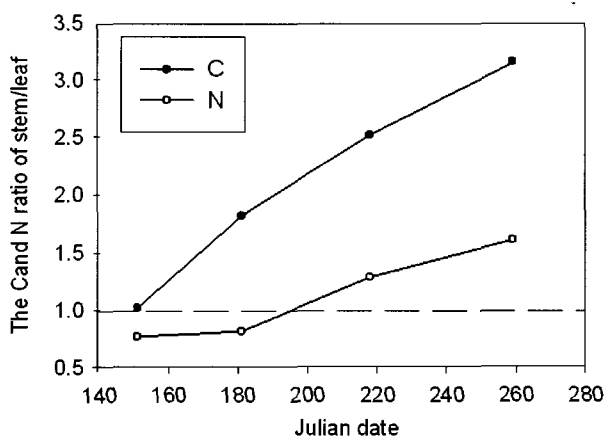


Fig. 8. N and C allocation of stem and leaf.

LITERATURE CITED

- Ågren GI. 2004. The C : N : P stoichiometry of autotrophs - theory and observations. *Ecol Lett* 7: 185-191.
- Chang NK, Yoshida S. 1973. Studies on the Gross Metabolism in a *Sasa paniculata* Type Grassland. *J Jpn Soc Grassl Sci* 19: 107-134.
- Cronk QCB, Fuller JL. 1995. *Plant Invaders: the Threat to Natural Ecosystems*. Chapman & Ha. New York. 241 p.
- Ehara K. 1955. Comparative morphological studies on the hop (*Humulus lupulus* L.) and the Japanese hop (*H. japonicus* Sieb. et Zucc). *J Fac Agric* 10: 209-237.
- Field C and Mooney HA. 1986. The photosynthesis-nitrogen relationship in wild plants. pp 25-55.
- Haukioja E, Ruohomaki K, Suomela J, Vuorisalo T. 1991. Nutritional quality as a defense against herbivores. *Forest Ecol Manage* 39: 237-245.
- Hickman J, Pitelka LF. 1975. Dry weight indicates energy allocation in ecological strategy analysis of plant. *Oecologia* 21: 117-121.
- Hur JY, Jeong CH, Shim KH. 2003. Chemical components of *Humulus japonicus* leaves and stalks. *J Agricul Life Sci* 37: 1-7.
- Hurt R. 1982. *Plant growth curves: a functional approach to plant growth analysis*. Edward Arnold, London.
- James W, Friedrich, Huffaker RC. 1980. Photosynthesis, leaf resistances, and ribulose-1,5-bisphosphate carboxylase degradation in senescing barley leaves. *Plant Physiol* 65: 1103-1107.
- Kawano S, Nagai Y. 1975. The productive and reproductive biology of flowering plants. I. Life history strategies of three *Allium* species in Japan. *Bot Mag Tokyo* 88: 281-318.
- Kull O, Jarvis PG. 1995. The role of nitrogen in a simple scheme to scale up photosynthesis from leaf to canopy. *Plant, Cell, Environ* 18: 1174-1182.
- Kwon GJ, Lee BA, Nam JM, Kim JG. 2006. The relationship of vegetation to environmental factors in Wangsuk stream and Gwarim reservoir in Korea: II. Soil environments. *Ecol Res* DOI: 10.1007/s11284-006-0188-4.
- Lambers H, Poorter H. 1992. Inherent variation in growth rate between higher plants: a search for physiological causes and ecological consequences. *Advan Ecol Res* 23: 188-242.
- Lutze JL, Gifford RM. 1998. Acquisition and allocation of carbon and nitrogen by *Danthonia richardsonii* in response to restricted nitrogen supply and CO₂ enrichment. *Plant, Cell, Environ* 21: 1133-1141.
- Marrs RH. 1978. Seasonal changes and multivariate studies of the mineral element status of several members of the Ericaceae. *J Ecol* 66: 533-545.
- Mattson WJ. 1980. Herbivory in relation to plant nitrogen content. *Annu Rev Ecol Syst* 11: 119-161.
- Medez M, Staffankarlsson P. 2005. Nutrien stoichiometry in *Pinguicula vulgaris*: Nutrient availability, plant size, and reproductive status. *Ecology* 86: 982-991.
- Ministry of Construction and Transportation. 2001. Report for River Environment Rehabilitation of Osan stream. (in Korean)
- Ohlson M, Staaland H. 2001. Mineral diversity in wild plants: benefits and bane for moose. *Oikos* 94: 442-454.
- Ohnmeiss TE, Baldwin IT. 1994. The allometry of nitrogen allocation to growth and an inducible defense under nitrogen-limited growth. *Ecology* 75: 995-1002.
- Reich P, Walters M, Ellsworth DE. 1992. Leaf life-span in relation to leaf, plant, and stand characteristics among diverse ecosystems. *Ecol Monogr* 62: 365-392.
- Reich PB, Walters MB, Tjoelker MG, Vanderklein D, Buschena C. 1998. Photosynthesis and respiration rates depend on leaf and root morphology and nitrogen concentration in nine boreal tree species differing in relative growth rate. *Funct Ecol* 12: 395.
- Seoul City. 2001. Close Investigation of Natural Ecosystems in Seoul. (in Korean)
- Thompson K, Parkinson JA, Band SR, Spencer RE. 1997. A comparative study of leaf nutrient concentrations in a regional herbaceous

- flora. *New Phytol* 136: 679-689.
- Tilman D. 1982. *Resource Competition and Community Structure*. Princeton University Press. Princeton, USA.
- van Andel J, Vera F. 1977. Reproductive allocation in *Senecio sylvaticus* and *Chamaenerion augustifolium* in relation to mineral nutrition. *J Ecol* 65:747-758.
- Wittenberg R, Cock MJW. 2001. *Invasive Alien Species. How to Address One of the Greatest Threats to Biodiversity: A Toolkit of Best Prevention and Management Practices*. CAB International. Oxon, UK.

(Received October 11, 2006; Accepted October 24, 2006)