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Original Research Paper

Study on the Shade-Tolerance Ability of *Glechoma hederacea*

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ABSTRACT

Planting understory groundcover plants has apparent ecological and agroforestrial benefits since it can greatly improve the ecological environment. However, this requires that the groundcover plants should have a certain shade tolerance. This study examined the shade tolerance of *Glechoma hederacea* by examining the light-utilization characteristics of it including the rate and state of its growth under different light conditions. The results showed that, *G. hederacea* has the lower light compensation point, the higher light saturation point, the maximum apparent quantum efficiency, and the maximum net photosynthetic rate, which reflected that *G. hederacea* had a wider use range of effective light radiation and a stronger shade-tolerance ability. In stronger light conditions, *G. hederacea* grew faster and had longer stems, shorter internodes, also the rooting and branching situations were better compared with that in weaker light. However, this plant grew normally in weaker light, and invasion of weeds was less prominent with well-growth. Thus, *G. hederacea*, as a kind of shade-endurance groundcover plant, was also adaptable to the full-light environment and could be used in the plant practice of forest interplanting, playing an important role in ecological diversity and environment protection.

INTRODUCTION

With increasing concern about the environment protection (Kamble & Awaghade 2011, Lang et al. 2013), understory groundcover plants have received much attention in recent years owing to forest interplanting, which has obvious ecological benefits. Firstly, understory groundcover plants, with thick foliage covering on the surface recover yellow soil, can effectively reduce the re-entrainment of dust and prevent soil erosion. In addition, planting understory groundcover plants can largely prevent the growth of weeds, and this consequently can reduce the use of pesticides, herbicides, and labour, thus meeting low-carbon requirements. Secondly, planting understory groundcover plants can significantly improve the green cover and the ability to improve the environment. Thirdly, these plants can increase species diversity and make the forest ecological system more stable. The key to successful planting of understory groundcover plants in forests lies in the shade tolerance of the groundcover plants chosen for planting. Therefore, study on the shade tolerance of groundcover plants has become the hot issue of academic concerns at home and abroad, but most of the current researches were focused on the comparison of the shade tolerance among different species regarding the shade-endurance groundcover plants (Wei et al. 2013, Zhang et al. 2004, Shozo et al. 1998, Wu et al. 1994, Bai et al. 1999, Zhang et al. 2009, Wang et al. 2005). There are few studies on the shade tolerance of specific groundcover plant.

Glechoma hederacea is a perennial herb of Labiatae. The stems with four edges are slender and branching. The kidney shaped or heart shaped leaves with long petiole and serrated edges are opposite. Two or six flowers are whorled in the leaf axils, and the corolla is bilabiate and lavender. Flowering occurs from May to June, and 4 small nuts are spherical (Institute of Botany 1987). *G. hederacea* is a good ornamental plant, during the flowering season, blue-purple flowers embellish among green leaves, it looks very elegant and lovely, and after the flowering season, the stolon and leaves cover the ground and can be used as the background of woodland. As a kind of wild groundcover plants, there are still shortage in depth and extent as to the exploration on *G. hederacea.* At present, studies on *G. hederacea* are rare, and the studies abroad that have been conducted mainly focused on its certain biological characteristics, such as its clonal growth and the biomass allocation strategy and so on (Stuefer & Hutchings 1994, Roiloa & Hutchings 2013). In addition to anatomical studies and karyotype analyses in China (Li et al. 2006, Tao et al. 2005), Zhang & Lin (2012) compared the shade-tolerance abilities of five groundcover plants, including *G. hederacea*, but further researches on its shade-tolerance are lacking in details. Moreover, in the past, researchers have described the shade-tolerance ability of groundcover plants as shadow tolerance, semi-shadow tolerance, side shading-requiring, shade-requiring and other emotional description. In planting, the design relies mainly on the plant cultivation experience and a thorough knowledge on its ornamental characteristics. Because, there is a lack of theoretical guidance and scientific investigations, many problems are often encountered in practice. From the perspective of light-utilization features of *G. hederacea* and its growth under different light conditions, specified theoretical and experimental analysis were conducted in this paper regarding the shade-tolerance ability of *G. hederacea*, in order to provide reliable data and technical support for forest intercropping and to promote the development of ecological recycling agroforestry.

MATERIALS AND METHODS

Study area: This research was conducted mainly in the flower nursery of Flower Research Institute and the campus of Northeast Forestry University. Harbin city is located in the southwest region of Heilongjiang province at latitude 45°41' and longitude 126°37'. It is 171.7 m above sea level with annual average temperature of 3.6°C and the annual range of air temperature of 41.6°C. The annual average water pressure is 7.8 hpa and the annual average relative humidity is 37%, with average annual volume of water 462.9 mm. The annual average sunshine time is 2,745.7 hours with annual mean ground temperature of 5.3°C. The annual frost-free period is 136 days (Yang 2012). The soil properties of the Institute of Flower Nursery are given in Table 1.

The determination of the characteristics of light energy utilization: The photosynthetic rate was measured by the COR6400 portable photosynthesis system (LI-COR, Inc., Lincoln, NB, USA). The plant material was obtained from the Flower Institute of Northeast Forestry University. The experiment was started at 9 a.m. on a sunny day; healthy leaves were chosen and determination was repeated three times, using LED artificial light of the photosynthesis measurement system, which made the effective radiation (îmol $m^{-2}s^{-1}$) increasing from 0 to 1,500, in order to determine the light-photosynthesis curve of *G. hederacea* (Fig. 1); and then calculated the light compensation point, light saturation point, the maximum apparent quantum efficiency and the maximum net light and rate.

Table 1: Soil features at the Northeast Forestry University Flower Research Institute (Yang 2012).

Depth of soil (cm)	Organic matter (%)	Ash (%)	Hygroscopic water (%)	Density (g/cm^3)	Total porosity (%)
0-5	6.07	93.93	1.98	0.78	70.53
5-10	5.43	94.57	1.50	0.74	72.23
10-15	5.10	94.90	2.48	0.82	69.13

The light compensation point was determined from the logarithmic curve fitting the light-photosynthesis curve light. Wang (1996) method was used to determine the light saturation point of plant, namely, when the changes of the net photosynthetic efficiency produced by the changes of each unit light intensity with μmol $m^{-2}s^{-1}$ were less than 0.004 μmolCO_2 $m^{-2}s^{-1}$, the light intensity was the the light saturation point of plant, and the net photosynthetic rate at this time was the maximum net photosynthetic rate. The apparent quantum efficiency is the slope of the light-photosynthetic rate curve, namely the ratio of the photosynthetic rate and the photosynthetic active radiation(PAR). The initial curve slope of the light-photosynthetic curve is the ratio of the photosynthetic rate and the photosynthetically active radiation in the lower range of photosynthetically active radiation (0-200 μmol photons $m^{-2}s^{-1}$) when the light quantum has no redundancy. Thus, the apparent quantum efficiency at this time was the maximum quantum efficiency (Wang 1996).

Statistically significant differences were examined with SPSS 10.0 statistical analysis software (IBM Corporation, Armonk, NY, USA). Microsoft Excel 2003 software (Microsoft Corporation, Redmond, WA, USA) was used for data reduction and plotting.

Survey Method of the Growth Rate Under Different Light Conditions

Investigation of the growth rates in different habitats: Thirty *G. hederacea* plants were planted in two types of environments with full light and understory. The planting spacing was 70cm × 70 cm. There was a 100% survival rate after one week, the first measurement was started two weeks later including the main branch length, the number of branches and their length, and the number of roots. Measurements were made every week for a total of eight weeks.

Survey of the coverage rate under different light intensities: Three kinds of shade net were created with black mesh, and the light transmittance of each treatment was measured with an illuminance meter (ST-85) on the sunny day. The three shade types were an all-optical control CK (light transmittance, 100%), T1 (light transmittance, 75%), and T2 (light transmittance, 10.42%). *G. hederacea* plants were planted in each pole with a spacing of 15 cm × 15 cm with a randomized block design. They were repeated 3 times, and the district area was 2 m^2. We began to measure the variation in the cover two weeks after survival and once

Table 2: Comparison of Light Compensation Point (LCP) of several groundcover plants.

Species	LCP (μmol $m^{-2}s^{-1}$)	Regression equation	Correlation coefficient (R^2)
Glechoma hederacea	23.9	$y = 2.54369 Ln(x) - 8.7789$	0.9776
*Hosta plantaginea**	65	$y = 1.6418 Ln(x) - 6.8506$	0.9720
*Trifolium repens**	76	$y = 2.1003 Ln(x) - 9.1083$	0.9479
*Liriope platyphylla**	26	$y = 0.8229 Ln(x) - 2.6749$	0.9683
*Hemerocallis middendorfii**	17	$y = 0.7275 Ln(x) - 2.0522$	0.9852
*Orychophragmus violaceus**	53	$y = 2.37 Ln(x) - 9.4082$	0.9531

Note: *y* is the photosynthetically active radiation (μmol $m^{-2}s^{-1}$); *x* is the photosynthetic rate (μmol CO_2 $m^{-2}s^{-1}$)
*Quoted from Wang (2005)

every two weeks, and this ended when the coverage was 100%.

Investigation with Respect to the Growth Situation Under Different Light Conditions

In the growing season, 30 plants were dug up at south of the forest edge and in the understory in the Institute of Flowers of Northeast Forestry University, being careful not to damage the roots, stems, leaves, and stem length and internode length were measured. The number of leaves, buds, roots, and branches and the growth situation were observed and recorded. The growth conditions of *G. hederacea* under different environmental conditions were compared.

ANALYSIS AND DISCUSSION

Characteristics of Light Energy Use

Light compensation point (LCP): The value of light compensation point, which directly reflects the plant's ability to use weak light, is an important evaluation index of plant shade tolerance. The light compensation points of *G. hederacea* and other herbaceous groundcover plants were compared as given in Table 2. We can see that *G. hederacea* has a lower light compensation point, suggesting that it can start the forward synthesis of organic matter under low light intensity and that it has a higher shade tolerance.

The light saturation point: The light saturation point is another important index that reflects the shade-tolerance ability of plants. Above the light compensation point, the photosynthetic rate increases linearly along with light intensity within a certain range. When added to a certain degree, the photosynthetic rate increases slowly along with light intensity. Finally, when it no longer increases, this point shows the light saturation phenomenon, and the light intensity at this point is called as light saturation point (Wang 1996). As given in Table 3, the light saturation point of *G. hederacea* was relatively higher, while the light compensation point was lower. This suggested that its use range of the effective light radiation was wide. In other words, it not only has a strong ability of shade tolerance, but it also has a certain light-requiring ability, showing a wide scope of strong light adaptation.

Maximum apparent quantum efficiency: The apparent quantum efficiency is the ratio of oxygen evolution rate of the leaf in a certain light or CO_2 assimilation rate and the photon flux density projected to the leaf surface, which reflects the light utilization efficiency of the plant under different illumination conditions. Table 3 showed that the maximum apparent quantum efficiency of *G. hederacea* was larger than those of the other species, and it has a high ability to absorb weak light.

Maximum net photosynthetic rate: The net photosynthetic rate at the light saturation point is the maximum net photosynthetic rate, which represents the plant's maximum capacity to assimilate carbon dioxide (Wang et al. 1991). Compared to the light-requiring plants, the shade-tolerant plants have lower maximum net photosynthetic rates regarding the photosynthesis curve. As can be seen in Table 3, of all the 6 kinds of plants, the net photosynthetic rate of *G. hederacea* was the second highest. These measurements illustrated that the effective use of light energy utilization was stronger in *G. hederacea*.

Investigation on Growth Rates of *G. hederacea* under Different Light Conditions

Comparison of growth rate under different light conditions: The growth curves under different light conditions in Fig. 2 showed that it entered into a rapid growth phase two weeks later after the transplant, during which the main branch extension length was up to 12.5 cm per week. The growth gradually slowed down after six weeks, but at that time, the branching growth increased (Figs. 3 and 4). Thus, this period nearly reached its close canopy, which also was the peak growing season of *G. hederacea*. Seventeen weeks later, its growing trend gradually declined and meanwhile due to some man-made causes (serious stampede), and the main branch growth almost stagnated while the branches continued to grow. In early October, the growth period ended, and

Table 3: The light saturation point (LSP), maximum apparent quantum efficiency (MAQE), and net photosynthetic rate of some species.

Species	LSP ($\mu mol\ m^{-2}s^{-1}$)	MAQE (ϕ)	Maximum net photosynthetic rate ($\mu mol\ CO_2\ m^{-2}s^{-1}$)
G. hederacea	65	0.0353	8.40
*H. plantaginea**	410	0.0172	4.5
*T. repens**	530	0.0140	6.5
*L. platyphylla**	210	0.0104	3.0
*H. middendorfii**	290	0.0244	3.5
*O. violaceus**	590	0.0172	8.5

Note: *Quoted from Wang (2005)

Table 4: Tiller and branches of *G. hederacea*.

Item	Total Length (cm)	Node Number	Internode Length (cm)	Rooting Ratio (%)	Bifurcation Ratio (%)
Main branch[1]	146.2	23.6	6.19	58	21.6
Main branch[2]	130.3	19.2	6.28	42	15.8
Lateral branch [1]	326.6	52.7	5.19	76	6
Lateral branch [2]	122.5	21.1	4.93	67	5.7

Note: [1]represents for the forest edge, [2]represents for underforest

some leaves began to drop. In addition, compared to understory condition, the stretching length of stolon per week in the full sunlight was much longer.

Increase rate of coverage in different light conditions: As can be seen from the increase curve of coverage under different light conditions in Fig. 5, *G. hederacea* grew more quickly under full light, and its coverage reached 100% after 45 days with a planting spacing of 15cm × 15 cm, while it needed two months at relative light intensity of 43.56%; for the relative light intensity of 10.42% the required time was still much longer.

Growth Situation of *G. hederacea* Under Different Light Conditions

As can be seen in Table 4, in stronger light condition, the stem of *G. hederacea* was longer, the internode was shorter, and the conditions for rooting and bifurcation were better than those in weaker light condition. The biomass of *G. hederacea* growing in the stronger light was higher than those in the weaker light. This suggested that *G. hederacea* was not a shadow-requiring plant, as it not only can grew better in the stronger light, but also grow normally in weaker light, this characteristics reflects its better shade- tolerance ability.

CONCLUSIONS AND RECOMMENDATIONS

1. The experimental results with respect to the light utilization characteristics of *G. hederacea* showed that, *G.*

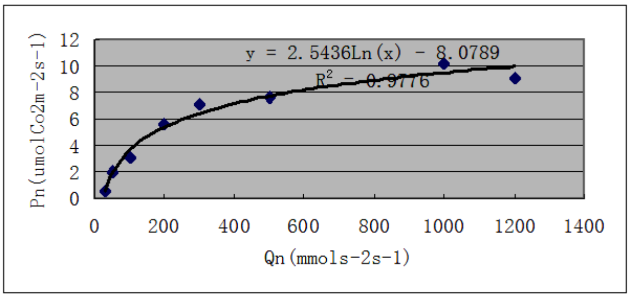

Fig. 1: The light intensity-photosynthetic diagram of *Glechoma hederacea*.

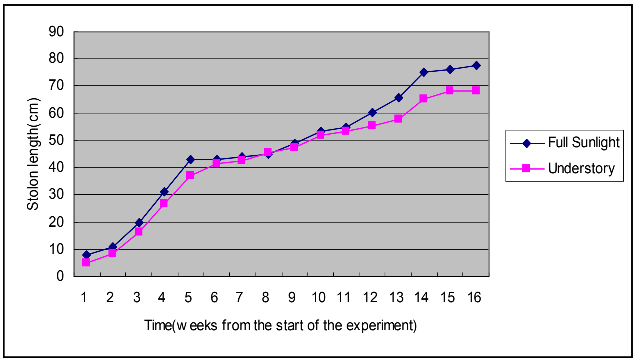

Fig. 2: *G. hederacea* growth curves in different light intensity conditions.

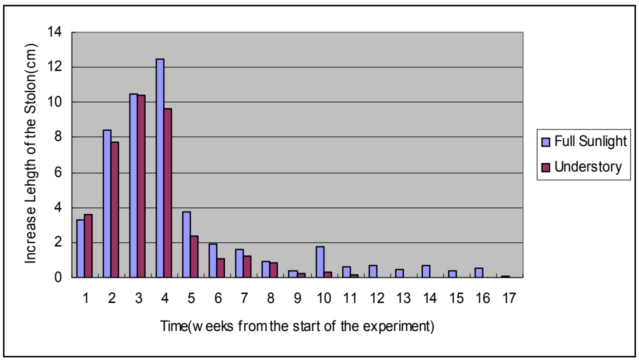

Fig. 3: Main stolon increase of *G. hederacea* in different light conditions.

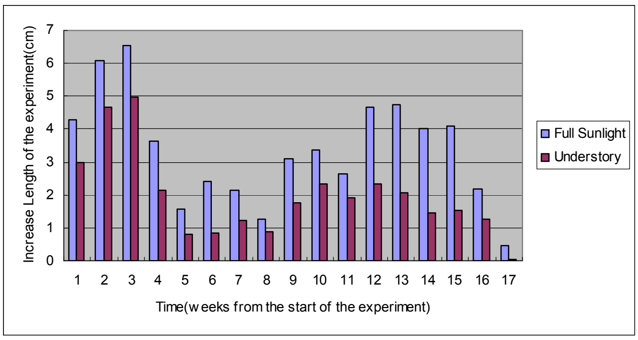

Fig. 4: Branching increase of *G. hederacea* in different light conditions.

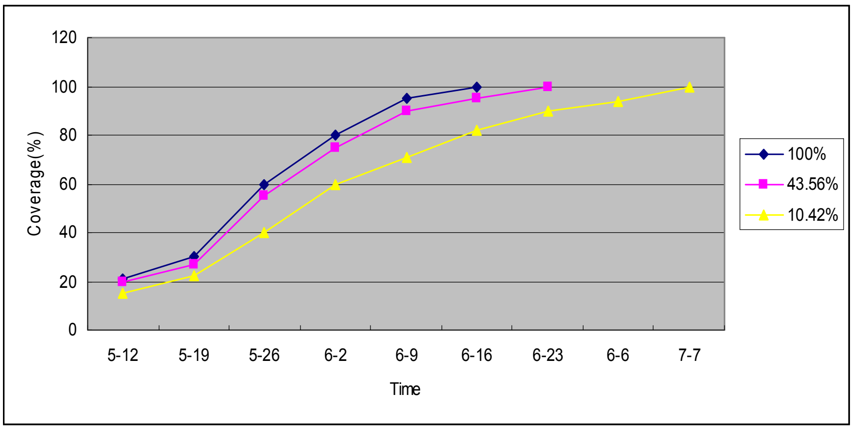

Fig. 5: Coverage increase curves of *G. hederacea* in different light conditions.

hederacea had a lower light compensation point, while the light saturation point, maximum apparent quantum efficiency and the maximum net photosynthetic rate were much higher, which reflected its wider use range of active light radiation. Owing to that it can grow well in full light condition or be planted in forests and so on, it can be prompted as shade-tolerance groundcover plant. Meanwhile, it can be planted under the deciduous trees during the compound planting pattern, which can significantly improve the ecological environmental pollution and keep the species diversity.

2. The comparisons of the growth rates under different light conditions showed that *G. hederacea* had strong vitality, and it can grow in any lighting conditions. In the case of stronger light, it grew faster. In the appropriate shade (43.56%), it grew well. When the planting spacing was 15 cm × 15 cm, the coverage reached 100% about 45 days later. It can be planted in stronger light conditions or be promoted as the understory groundcover plants.
3. From the perspective of growth situations of *G. hederacea* under different growing environments, in the case of stronger light, the stem of *G. hederacea* was longer, the internode was shorter, and the conditions of rooting and bifurcation were better than those in weaker light. In addition, we observed that whether under the forest or in other types of shades, *G. hederacea* grew well with the dark green leaves, and the weed invasion was difficult, so the attractiveness of this plant was higher. This further illustrated the stronger adaptability of *G. hederacea* to light. Thus, it was suitable to be planted as groundcover plants in open forest or intercropped with “tree + grass” pattern.
4. This experiment was completed in Harbin, which is located at the high altitude areas in China, where the climate conditions are worse, few plant species can be used, and species of understory groundcover plants are rare. During the experiments, we found that *G. hederacea* peeped through the soil and turned green in early April, and until late October, the leaves and stems wilted. Thus, its green period is long with highly ornamental value, meanwhile owing to it can adapt to the climate of high and cold areas, it can be promoted in high and cold areas of north China.
5. With the understory planting of *G. hederacea*, we can improve the green quantity of ecological environment, meanwhile covering the bare land and making the woodlands more beautiful and more attractive for people. The stolon of *G. hederacea* will root when it meets soil with stronger covering capacity, it can reduce weed invasion and prevent the loss of water and nutrients, and also its leaves have a volatile oil that can repel mosquitoes, effectively reducing the frequency of pests and diseases. Thus, it is a good groundcover plant that is suitable for wide promotion. However, due to limited research time and conditions, this study only analysed the light utilization characteristics and growth of *G. hederacea* in different light conditions, and failed to analyse the relevant physiological mechanisms of shade-tolerance. In addition, in order to conduct scientific understory intercropping, we also need to master the relevant knowledge about the features of the soil fertilization and water that the plant needs, and the root distribution characteristics and so on. A follow-up study will, therefore, be commenced with an in-depth analysis considering the mixed planting of multiple understory plants and their interactions in order to provide technical support for scientifically conducting the understory intercropping and the development of ecological recycling agroforestry.

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