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ARTICLE

Carbon dioxide absorption for *Liriodendron tulipifera* using fertilization

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Abstract We conducted this study to obtain the basic information for forest biomass estimation in a national unit by predicting the carbon dioxide absorption of the early growth of *Liriodendron tulipifera* based on several fertilization methods. The study site, located in Gimje-si, Jeollabuk-do, consisted of 11 fertilizer treatment plots, repeated three times by species. Five sample trees were planted in each plot, and a total of 165 sample trees of each species were planted. Of these sample trees, every two samples of the *L. tulipifera* were cut down in order to estimate the biomass. The results were similar to the analysis results for the mean volume. In comparison to the control group with a biomass of 310.35 g, the biomass of the LLF and HLF groups was relatively high, whereas the biomass of the CF and CP groups was relatively low. As a result, the LLF-150 group had the highest biomass at 96.36 g, and all of the treatment groups had higher biomasses than the control group (16.14 g) in the case of branches. In the case of leaves, the HLF-150 group had the highest biomass at 239.48 g and the CP group had the lowest biomass at 115.60 g. In the case of roots, the LLF-150 group had the highest biomass at 495.45 g, and only the CP group (186.82 g) had a lower biomass than the control group (194.90 g).

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Introduction

We conducted this study in order to collect the basic information for forest biomass estimation in a national unit by predicting the carbon dioxide absorption of the early growth of *Liriodendron tulipifera* based on several fertilization methods.

Greenhouse gas emissions have increased 136 % in Korea over the past 20 years, and this country has the third highest increase after the countries China (256 %) and India (179 %) where greenhouse gases have increased rapidly. Korea has not yet decided to join the target countries for reduction obligations in the second commitment term, but it is likely to become a target country of reduction obligations in 2020 when a climate regime is established (KFRI 2012).

Likewise, investigations of forests that have a high impact on carbon fixation and the production of biomass are needed because the concern for forests is increasing. The unit of a country's forest biomass is estimated on the basis of the tree accumulation measured by the National Forest Inventory. In addition, the carbon absorption of a forest is measured using the carbon conversion coefficient (Tomppo 2000; Son et al. 2007).

In light of this situation, Korea has created a bio-circulation forest in order to reduce carbon dioxide. *L. tulipifera* is a major species in the bio-circulation forest. In 2002, *L. tulipifera* was selected as one of the 20 afforestation recommended trees, and the cultivating technology and mass propagation by culturing the cells of

L. tulipifera have been studied (Ryu et al. 2003; Ryu and Kim 2003; Lee et al. 2003). Research has shown that *L. tulipifera* in particular has a high level of conversion of energy to bio-energy. For this reason, research to produce bio-energy from *L. tulipifera* has been actively promoted in Korea (Shin et al. 2009a, b; Kim et al. 2009). There are 6116 ha of bio-circulation forests that were afforested by 2009 in Korea. With the expansion of the bio-circulation forests' afforestation, the Korea Forest Service has devised a plan for annual afforestation to construct 100,000 ha of bio-circulation forests before 2020 in order to develop effective bio-circulation forests (KFS 2011). The *L. tulipifera*'s afforestation area was 1020 ha of the total 20,744 ha of the afforestation area planted in 2007. However, with a continuous increase, it has grown to 4583 ha, corresponding to 21 % of the total 21,179 ha of the afforestation area in 2011 (Kang et al. 2013).

Therefore, *L. tulipifera* has a large impact on biomass production and carbon dioxide fixation. Various studies on *L. tulipifera* have been conducted for this reason. However, research on the analysis of the early growth of *L. tulipifera*'s biomass estimation and carbon absorption of forests was non-existent until now.

Forest stand biomass is distinguished by a variety of environmental factors, such as the physiological and genetic characteristics of the species, the age of the stand, the stand density, and the conditions of the location and climate. In addition, a plantation's soil types, moisture, light, temperature, and planting method, as well as the planting time, fertilization, and management of lower vegetation, have a significant effect on the achievement of afforestation (Lee et al. 2006). In particular, each species' age and state of growth, as well as the plantation's low vegetation's proper fertilization and fertilization technology that is suitable for the location's environment, are major factors for the achievement of afforestation.

Materials and methods

Preparation of study site

In order to estimate the biomass output of the trees by the fertilization method, we prepared a study site located at San 1-1, Sang-ri, Baeksan-myeon, Gimje, Jeollabuk-do (N 35°51′06.24″, E 126°56′00.38″), in 2012 (Fig. 1).

The treatment groups were divided into the control group (non-treatment group), a chemical fertilizer (CF) group, a compost (CP) group, a low liquid fertilizer group (LLF), and a high liquid fertilizer (HLF) group. For the test, the LLF and HLF groups were made one time, one and a half times, and two times, respectively, as much as the proper fertilization criteria set by National Institute of Animal Science (2007). A total of nine treatment groups, each tested three times, were prepared in this study.

In order to prevent the effects of the withering rate caused by a low survival rate in this test, 2–2 seedlings were planted in 2012 to get them adapted to this study site. Five trees were planted for each plot, and therefore, 135 trees (5 trees × 3 times repetition × 9 treatment groups) were planted according to species of trees (Fig. 2).

Fertilizer distribution by fertilization method

The trees were fertilized from April to October 2013, since the saplings came into leaf fully and began to grow at that time. Regarding the fertilization methods, whole layer fertilization was applied to the CF group, surface fertilization was applied to the CP group, and the earth surface drip irrigation method was applied to the LF groups. The number of fertilization times was different depending on the types of fertilizer. In the case of chemical fertilizers, basal fertilization (April), 1st additional fertilization (June), and 2nd additional fertilization (August) were applied. In the case of compost, fertilization was applied six times: two times in April, one time in May, one time in August, one time in September, and one time in October. In the case of liquid fertilizers, fertilization was applied once every week (a total of 18 times) from April to October, except for during the rainy season (the 3rd week of June to the 2nd week of August). Cylinders that were 50 cm in diameter were placed around the saplings for the treatment groups in order to prevent the liquid fertilizer from flowing over the soil surface (Tables 1, 2, 3).

Estimation of biomass

In order to survey each biomass output of the *L. tulipifera* by fertilization method, we selected every two sample trees per one plot; total six samples for each treatment group. Those were cut down and dissected into each part of tree (stem, branch, twig + leaf, and root). Stem is divided into each 30 cm length, and stem volume was estimated using Smalian's formula. In the laboratory, they were dried at 85 °C using Forced Convection Programmable Dry Oven (FCPO560, Lab House, Dongseo Science Co., Ltd, Korea), and then each organ's dry weight meaning biomass was measured. Stem density (SD) was calculated using these volume and dry weight, which is a factor used for converting volume into biomass (Kim 2011). The component biomass expansion factors were estimated using the ratios of the partial biomass to the stem biomass.

Statistical analysis

In order to analyze how the CF, CP, LLF, and HLF treatments affected the growth of *L. tulipifera* in this study, we

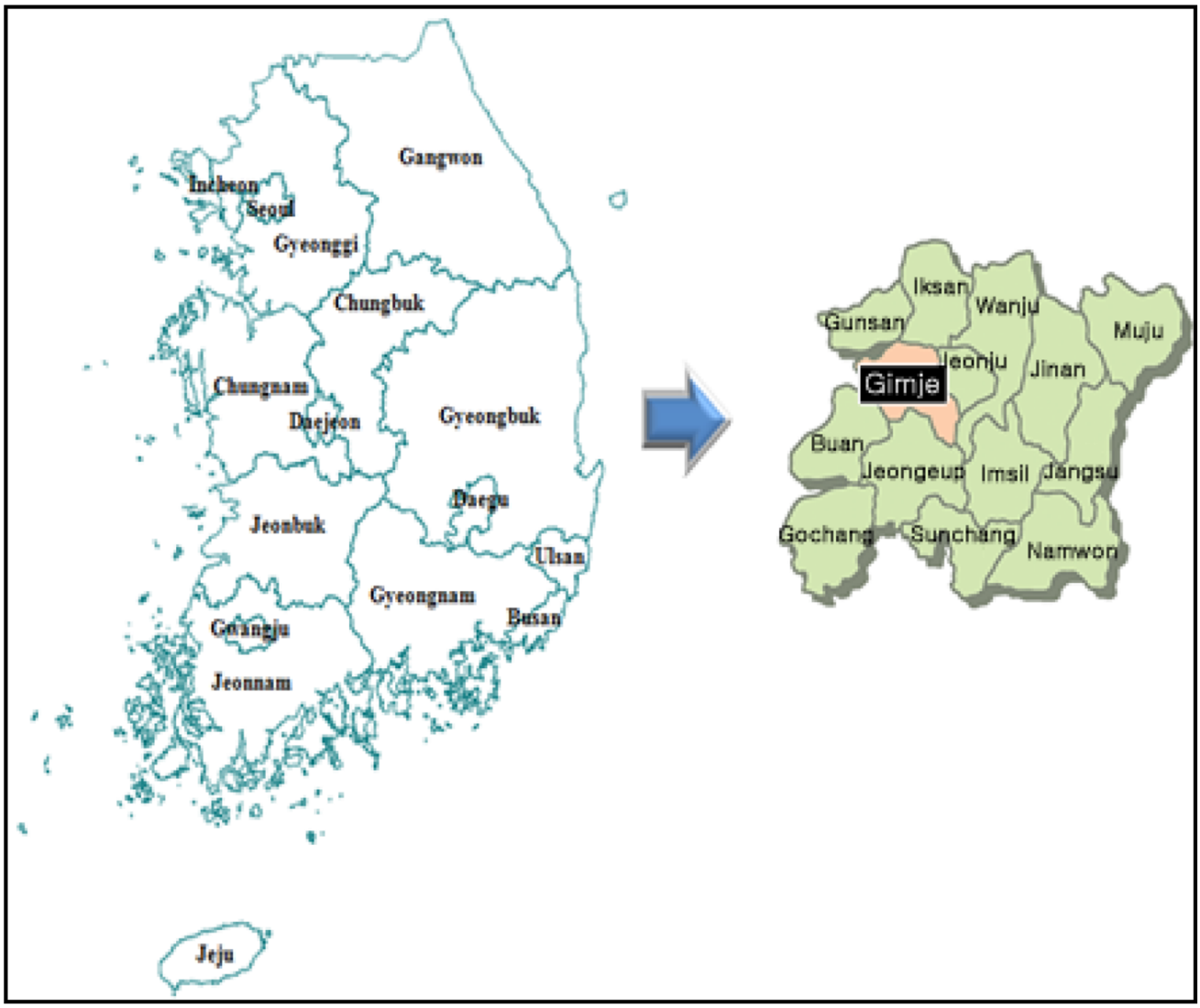

Fig. 1 Study area

employed SAS ver. 9.3 (Statistic Analysis System) to conduct a one-way variance analysis using PROC ANOVA procedure on the total growth amount, volume, stem density, and biomass expansion factor (BEF) of each treatment group.

Results and discussion

Biomass analysis by fertilization method

The average volume of *L. tulipifera* was calculated for each treatment group. As a result, the average volume of all of the LF groups was higher than that of the control group (617 cm^3). In the LF groups, the average volume growth amount was investigated in terms of density. In the LLF and HLF groups, the volume growth amount tended to first increase and then decrease as the amount of distributed liquid went up. It was determined that this result was attributable to the bad influence of the soil residual from the massive amount of liquid fertilizer that was distributed. Therefore, it is necessary to do further research on the most efficient amount for distribution.

Meanwhile, the mean volume growth amount of the CF group was not greatly different from that of the control group, and the volume growth amount of the CP group was lower than that of the control group. It was determined that this result was attributable to the effects of the compost gas. Therefore, it is necessary to pay more attention to compost use.

The stem density of *L. tulipifera* was calculated from the fertilization group. As a result, the control group had the

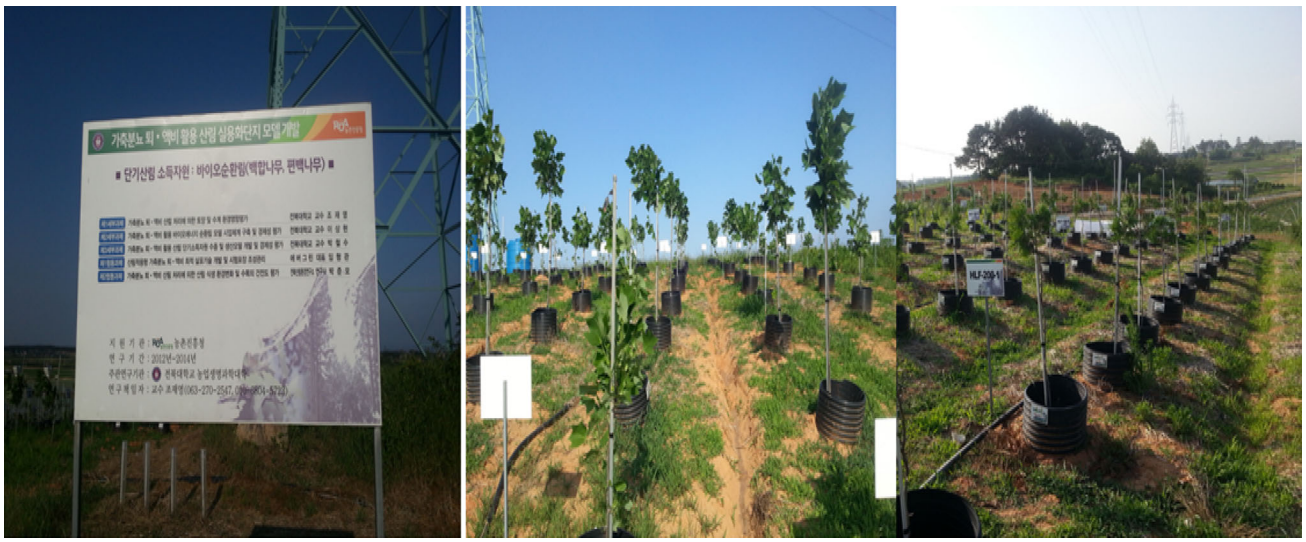

Fig. 2 Panorama of experimental field

Table 1 Amount of the applied chemical fertilizer by N, P, and K

	Basic fertilization (g)	Additional fertilization (g)	
		1st	2nd
N	10.83	5.42	5.42
P	50.00	–	–
K	16.60	8.30	8.30

Table 2 Amount of the applied compost, low liquid fertilizer, and high liquid fertilizer

Treatment plot (%)	100	150	200
CP (g)	67	100.5	134
LLF (ml)	380	570	76
HLF (ml)	130	200	260

Table 3 Chemical characteristics of CP, LLF, and HLF

Treatment plot	N (%)	P (%)	K (%)
CP	0.90	1.49	0.19
LLF	0.12	0.09	0.15
HLF	0.31	0.24	0.33

highest stem density of 0.503 and the LLF-150 group, which had the highest volume growth amount, showed the lowest density (0.385). Such a phenomenon appeared primarily in fast-growing trees, which had quick growth speed. It was determined that this result was attributable to the negative correlation between the diameter growth amount and the density.

Table 4 Mean *D*, mean *H*, mean *V*, SD, and stem biomass for *Liriodendron tulipifera* by the fertilization method (cm, m, m^3, g/cm^3)

Site	Mean D^a	Mean H^b	Mean V^c	SD^d	Stem biomass
CON	2.83	2.29	617^{cd}	0.503^a	310.35
CF	2.65	2.49	613^{cd}	0.465^a	285.05
CP	2.52	1.95	499^d	0.472^a	233.53
LLF-100	2.82	2.13	698^{bcd}	0.468^a	326.66
LLF-150	3.97	2.62	1775^a	0.385^a	683.38
LLF-200	2.78	2.82	723^{bcd}	0.501^a	362.22
HLF-100	2.99	2.40	738^{bcd}	0.437^a	322.51
HLF-150	3.48	2.82	1130^b	0.449^a	507.37
HLF-200	3.34	2.64	960^{bc}	0.417^a	400.32

[a] Mean diameter, [b] mean height, [c] mean volume, [d] stem density

Although the CF group and the CP group had a low growth amount, their density was lower than the density of the control group. Given that density represents the ratio of dry weight to volume, it was determined that the moisture contents of the standard tree stems of the CF and CP groups were relatively higher than that of other groups. Therefore, we determined that additional studies will be necessary on the fertilization effects of CF and CP, and the fertilization with liquid fertilizer has been determined to be the most effective.

The tree stem biomass was calculated for the treatment group of *L. tulipifera*. The calculated result was similar to the analysis result of the mean volume. In comparison to the control group, which had a biomass of 310.35 g, the biomass of the LLF and HLF groups was relatively high, whereas the biomass of the CF and CP groups was relatively low.

Table 5 The ANOVA procedure for *V* and SD of *Liriodendron tulipifera*

Source	*df*	Sum of squares		Mean square		*F* value		Pr > *F*	
		V	SD	*V*	SD	*V*	SD	*V*	SD
Model	8	2.461539	0.02343	0.307692	0.00292	9.55	0.90	0.0014	0.5535
Error	9	0.290007	0.02928	0.032223	0.00325				
Total	17	2.751546	0.05272						

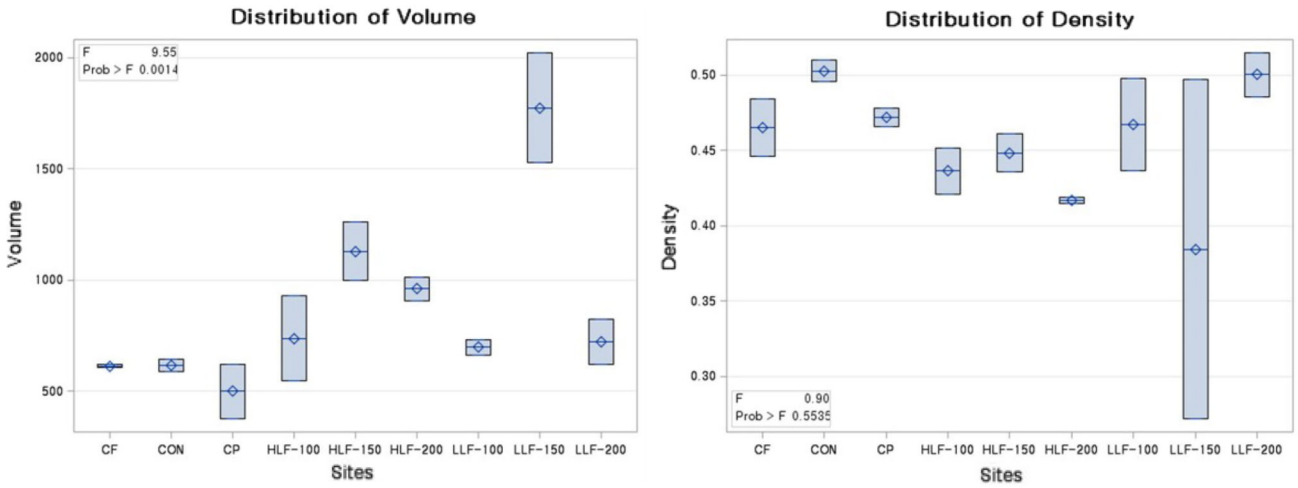

Fig. 3 Distribution charts of V and SD of *Liriodendron tulipifera* by the fertilization methods

Table 6 Partial BEF and biomass of *Liriodendron tulipifera* by the fertilization methods

Site	Stem biomass (g)	Partial BEF			Partial biomass (g)		
		Branch	Foliage	Root	Branch	Foliage	Root
CON	310.35	0.052	0.430	0.628	16.14	133.45	194.90
CF	285.05	0.129	0.591	1.037	36.77	168.46	295.60
CP	233.53	0.126	0.495	0.800	29.42	115.60	186.82
LLF-100	326.66	0.168	0.370	0.726	54.88	120.86	237.16
LLF-150	683.38	0.141	0.284	0.725	96.36	194.08	495.45
LLF-200	362.22	0.060	0.350	0.807	21.73	126.78	292.31
HLF-100	322.51	0.055	0.461	0.873	17.74	148.68	281.55
HLF-150	507.37	0.125	0.472	0.763	63.42	239.48	387.12
HLF-200	400.32	0.149	0.494	0.805	59.65	197.76	322.26

Therefore, it was determined that the liquid fertilizer positively affected the growth and biomass of *L. tulipifera*, and was more effective than CF and CP. However, if the amount of liquid fertilizer is too much, it may lower the growth amount and biomass of the trees, or reduce the fertilization effect. Therefore, the result of this research showed that proper fertilization is important (Table 4).

In order to study the differences in the volume and biomass output according to the fertilization methods of *L. tulipifera*, we employed SAS ver.9.3 to conduct an ANOVA on the data of the standard trees for each treatment group in this study. In the case of the mean volume growth amount of *L. tulipifera* by treatment group, the *F* value was 9.55 ($F > 0.95$), and therefore, the hypothesis was rejected. In other words, we could not determine that "there was no difference in the mean volume growth amount of *L. tulipifera* in regards to the fertilization method." In addition, the significance probability was 0.0014, and therefore, at the significance level of 0.05, the LLF-150 group and HLF-150 group were significant. However, in the case of the stem density, the *F* value was 0.90 ($F < 0.95$), and therefore, the hypothesis was

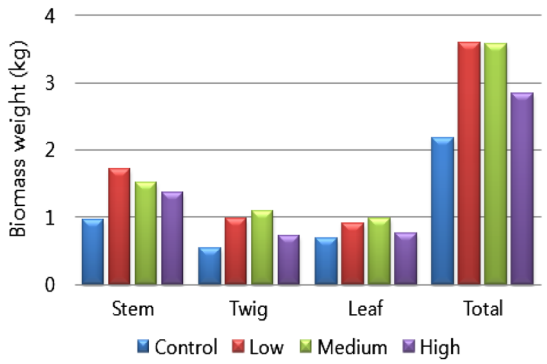

Fig. 4 Effect of SCBLF treatment amounts on biomass weight of yellow poplar (Kim et al. 2011)

accepted. In other words, it was fair to say that "there was no difference in the stem density of *L. tulipifera* in regards to the fertilization methods" (Table 5; Fig. 3).

Calculation of BEF and biomass of each organ by fertilization method

The BEF of each *L. tulipifera* organ was estimated for each of the fertilization methods. As a result, the highest BEF was determined to be the root, followed by the leaf and then the branch. It was determined that this result was attributable to the survival strategy of first generating the organ most necessary for growth and development in the early growth stage. The BEF of each treatment group was analyzed. As a result, in the case of boughs, all of the treatment groups had a higher BEF than the control group (0.052); in the case of leaves, only the LLF group had a lower BEF than the control group (0.430); and in the case of roots, all of the treatment groups had a higher BEF than the control group (0.628). Therefore, it was determined that fertilization not only affects the growth of tree stems, but it also influences the growth of the branches, leaves, and roots.

The biomass of each *L. tulipifera* organ was estimated for each treatment group. As a result, in the case of branches, the LLF-150 group had the highest biomass at 96.36 g, and all of the treatment groups had higher biomasses than the control group (16.14 g); in the case of leaves, the HLF-150 group had the highest biomass at 239.48 g, and the CP group had the lowest one at 115.60 g; and in the case of roots, the LLF-150 group had the highest biomass at 495.45 g, and only the CP group (186.82 g) had a lower one than the control group (194.90 g). Overall, it was determined that the LLF-150 treatment method was the most effective for increasing the biomass of each of the tree organs (Table 6).

In the case of *L. tulipifera*, the higher the distribution amount, the higher the biomass output. However, when 150 % of the proper fertilization amount was distributed, the highest output was produced, and at 200 % of the proper distribution amount, the output decreased again. According to the results of this study, the fertilization effects on the biomass output according to the distribution amount were similar to the results of previous studies (Kim et al. 2011; Fig. 4). The effects of the distribution amount were also judged to be larger than that of the liquid fertilizer density. Given the results noted above, the various mineral elements of liquid fertilizer, such as nitrogen, phosphorous, and exchangeable cations, positively affected the growth of *L. tulipifera*. Therefore, it was determined that treatment with liquid fertilizer is appropriate. However, excessive distribution of liquid fertilizer can reduce the fertilization effects or negatively influence the growth of trees. Therefore, proper fertilization is important. As a result, additional studies are needed in order to estimate the proper amount of liquid fertilizer.

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