The Influence of Larch-soybean Intercropping on the Growth Characteristics of Xingan larch Plantations in Northeast China

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Abstract

The objective of this study was to investigate the capacity for soil fertility improvement and larch growth promotion in a larch-bean intercropping system involving Xingan Larch (*Larix gmelinii* Rupr.) and soybean (*Glycine max* (L.) Merr.) in northeast China. Compared to the larch only plot, the larch-soybean intercropping had decreased soil bulk density, increased soil porosity and water content. It also significantly increased the soil organic matter, and there was found an increasing in soil nutrient content including available nitrogen, phosphorous and potassium. As a result of these soil improvements after soybeans were added to the larch plantations, greater height and diameter growth rates were observed in larch trees. The light saturated net photosynthetic rate of larch in a 9 year-old larch-soybean plot was 8.25 μmol $m^{-2}s^{-1}$, but it was only 7.2 μmol $m^{-2}s^{-1}$ in 9 year-old pure larch plots. The net photosynthetic rate and accumulation rate were significantly higher in the larch-soybean plots compared with pure larch plots. It is concluded that the intercropping of soybeans has the potential to improve soil fertility and promote larch growth in northeast China.

Key words: *Larix gmelinii*, soil fertility, photosynthetic production, tree-crop interactions, tree growth

Introduction

Northeast China is the largest and most important forest region in China. However, over a half-century forest exploitation and a policy of monoculture in China has led to the marked decline of total area and unit area stocking of natural forest (Zhang *et al*. 2000). The area of natural forests declined to 30% of the total forest area and unit-area stocking of natural forests decreased by 32%. Thus, the Chinese government began promoting planting of fast-growing tree species, such as larch (*Larix* sp.), poplar (*Populus* sp.) and Chinese fir (*Cunninghamia lanceolata* (lamb) Hook) to meet the increasing demand for wood by the nation's growing population.

As a fast-growing tree, Xingan larch (*Larix gmelinii* Rupr.) has been planted intensively for supplying the industrial needs of northeast China. Soybeans (*Glycine max* (L.) Merr.) were introduced to larch plantations in order to promote larch growth and the conservation of forest lands, to prolong the cycle of soil using because intercropping enhances the soil fertility by the nitrogen fixation. Soybeans with its symbiotic nitrogen-fixing bacteria within root nodules are highly nutritious crop containing 35-40% protein, 15-20% fatty acid and 20-30% carbohydrates. As an important food crop, soybeans have been planted extensively in northeast China. Before intercropping started, the native forest soil was badly damaged with unstable aggregate structure, acidification and the low fertility of soil because of forest exploitation and monoculture.To improve forest soil fertility and land conservation, the interactive effect between Xingan larch and soybeans has been considered as a key of new agro-forestry system. To explore the feasibility of this new system in northeast China, a better understanding of the larch-soybean interaction is urgently needed.

Agro-forestry systems have been examined by Anderson and Sinclair (1993) and Nair *et al*. (1994) from an ecological perspective and by Ong and Huxley (1996) from a physiological perspective. Many studies have shown that the trees introduced into agricultural fields can contribute to enhancing carbon sequestration in the tree-crop intercropping system (Kaya and Nair 2001, Kwesiga and Coe 1994, De Costa and Surenthran 2005). In general, during the early stages of agro-forestry system, attention has usually focused on the food crop yield in a tree-crop intercropping system. However, the effects of the food crop on the tree growth are still not well understood. It is expected that the introduction of soybeans will improve soil fertility of larch plantations in northeast China because the soybean litter with its high nitrogen content will enrich the nutrient status of forest lands for at least a few years. Net photosynthetic rate of larch trees accompanied with soybeans is expected increase along with higher nutrients in plant tissues.

In the study, soybeans were planted for 3 years in 9-year-old larch-soybean plantations and for 2 years in 4-year-old larch-soybean plantations. To assess the changes in the edaphic conditions of larch plantations

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and in the primary productivity of larch trees in a larch-soybean intercropping agro-forestry system, we monitored growth rate of larch trees in plantations of different ages and measured photosynthetic capacity of larch trees.

Materials and Methods

Study site description

This research was conducted in the Zhushan Experimental Forests, in northeast China (46.14°N, 129.41°E, 250 m a.s.l.) from 1998 to 2000. The research site has a typical continental monsoon climate with a mean annual precipitation of 562 mm, which is concentrated as rain in July and August. The annual mean air temperature ranges from 2.0 to 3.7°C with maximum and minimum temperatures of 35.0°C and –37.2°C, respectively. The soil at the research site is mainly a dark-brown forest soil.

Plantation design and establishment

This study was conducted at three plantations: a four-year old larch-soybean plantation (4LB), a nine-year-old larch-soybean plantation (9LB) and a nine-year-old pure larch plantation (9L). The three plantations were adjacent to each other, the area of plots in 9LB and 9L was about 0.6 ha each, and for 4LB was about 1 ha." The plant spacing of larch plantations is 1.5 m and the row spacing is 2 m. Two rows of soybeans were intercropped between two rows of larches. We assigned three replications per sample plot, and the plot size was about 400 m^2.

Soil physical and chemical properties

Soil bulk density of the topsoil (0-15 cm) and deeper soil (15-30 cm) was measured by core sampling. Four core samples were taken per plot. The Walkley and Black method (1934) was used to determine soil organic matter content in topsoil and deeper soil. The N concentration of topsoil and deeper soil were analyzed using an N-C analyzer (NC900, Shimadzu, Kyoto, Japan). Available phosphorus and potassium contents of topsoil and deeper soil were measured using the Bray method (phosphorus) (Van Ranst *et al.* 1999) and using flame photometry (potassium) after digestion with concentrated sulfuric acid.

Measurement of tree growth and photosynthesis

Mean height, mean basal diameter and mean diameter at breast height (DBH) of larch trees were measured from 1998 to 2000 on 50 trees randomly selected in each 9L and 9LB plots to determine treatment impacts on growth rate.

CO_2 assimilation rates were measured using a Li-Cor photosynthesis system (LI-6400, Lincoln, NE, USA). The light-saturated rate of CO_2 assimilation was measured at ambient CO_2 concentration. We preset the PPFD (Photosynthetic Photon Flux Density) to 1500, 1000, 600, 300, 200, 100 and 0 μmol $m^{-2}s^{-1}$ with a Li-Cor 6400-02B red/blue light source fitted to the leaf cuvette. The CO_2 saturated photosynthetic rate was measured at nearly saturated PPFD of 1000μmol $m^{-2}s^{-1}$ (Farquhar and Sharkey 1982, Sharkey 1985). All measurements were made at ambient air temperature and relative humidity. For each treatment three individuals of larch were measured. After measurement of gas exchange the needles were kept fresh until the needle area was determined. Light-saturated rate of CO_2 assimilation at an ambient CO_2 concentration were then calculated on a needle area basis. The area of fresh needle was scanned and determined with Area Meas (Hongu, Akinori MYKA. Lab.1.01 Ver, 1995). The photosynthesis parameters were mainly measured in August 1998, when the needles of larch each plot were matured. Measurements were taken on the south-faced side and top of trees per 10-days period. The mean value of each photosynthesis parameter measurements was used to analyze treatment difference.

Assimilation rate per day (ARPD) showed the integral value of unit needle net photosynthetic rate for daylight per day. Gross assimilation per stand (GAPS) was calculated as the total needle areas unit stand. Accumulation of assimilation per day (AaPD) and Photosynthetic yield (PY) were formulated here:

$$AaPD = ARPD \times GAPS$$
$$PY = AaPD \times NLPH$$

NLPH showed the number of larch trees per ha. Consumption rate per day (CRPD) was the integral value of unit leaf net respiration rate per day due to respiration. Three samples per stand in each plot were measured for net photosynthetic rate and respiration rate. For assimilation per day, we have measured net photosynthetic rate every hour per day. The areas of 50 random needle samples have been measured per stand per plot for gross assimilation per stand.

Statistical analysis

The mean values of tree height, basal diameter and diameter at breast height were analyzed using nested procedure of the SAS software (SAS Institute, Inc., 1996). Analysis of variance (ANOVA) was used for balanced data, and the general linear model (GLM) for unbalanced data.

Results

Tree growth analysis

To test the influence of tree-crop interaction, which is the abbreviation of tree and crop intercropping system, on larch growth we investigated the growth conditions of 50 randomly selected trees in the 9L and 9LB plantation. As Table 1 shows, mean tree height in 9L was significantly lower than that in 9LB, just at 44% of the mean tree height measured in 9LB. Mean basal diameter of larch in 9L was only 71% of diameter of larch grown in 9LB.

The patterns of tree height distribution in larch were analyzed for both 9L and 9LB plots (Figure 1a). In 9LB plot, the maximum height distribution was between 1.5 and 2.5 m while the maximum height distribution was between 0.5 and 1.5 m in 9L plot.

The patterns of basal diameter distribution were analyzed at 9LB plot and 9L plot (Figure 1b). Most basal diameter values in 9LB plot were varied from

Table 1. The tree growth survey between a nine-year-old pure larch forest (9L) and a nine-year-old larch-soybean forest (9LB).

Sample plot type	Exposure	Density (number ha^{-2})	Mean height (m)	Mean basal diameter (cm)	Mean diameter at breast height (cm)
9L	Northeast	3300	103.78b	2.4b	1.28b
9LB	Northeast	3300	235.64a	4.62a	0.58a

Values with the same letter (a, b) within a column are not significantly different from each other at P<0.05 (Least Squares Means using SAS analysis). All values are means of fifty replicates.

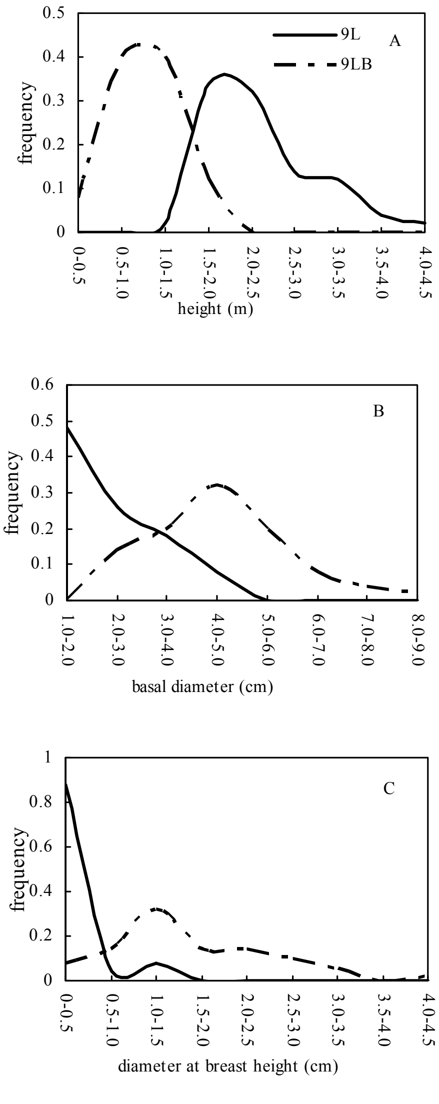

Fig. 1. Size distribution of larch trees in a nine-year-old pure larch forest (9L) and a nine-year-old larch-soybean forest (9LB). A, height distribution pattern; B, basal diameter distribution pattern; C, the diameter at breast height distribution pattern.

4cm to 5cm, which occupied 32% of the trees. However, basal diameter values in 9L ranged from 1 to 2 cm, which was represented by 48%of the sample trees.

To assess the diameter growth in the 9L plot and 9LB plot, we also analyzed the distribution patterns of diameter at breast height in both plots (Figure 1c). The percentage of larger diameter at breast height was significantly higher in 9LB plot than that in 9L plot. Moreover, the number of trees reached 0.5 cm to 1.5 cm of DBH was much larger in 9LB plot than in 9L plot.

Soil physical properties

Soil bulk density, soil porosity and soil water content in the topsoil (0-15 cm) and deeper soil (15-30 cm) were tested and results are shown in Table 2. Soil bulk density both in topsoil and in deeper soil were declined in 9LB and 4LB plots compared with 9L plot. However, there was no significant difference in soil bulk density values among 9L, 9LB and 4LB plots. Soil porosity in the topsoil was significantly higher in 9LB and 4LB plots than that in 9L plot.

In the deeper soil, soil porosity was significantly higher in 4LB plot than that in 9L and 9LB plots. There was significantly higher soil water content of the topsoil in 9LB and 4LB plots than that in 9L plot. The soil water content in deeper soil was significantly lower in 9LB and 4LB compared to 9L plot.

Soil organic matter (SOM) values of topsoil and deeper soil were highly variable among 9L, 9LB and 4LB plots (Figure 2). The values compared showed that the intercropping of soybean increased soil organic content in both topsoil and deeper soil.

Soil chemical properties

Soil pH values showed significant variation among 9L, 9LB and 4LB plots (Figure 3). The tree-crop intercropping had increased soil pH in both topsoil and deeper soil. Total nitrogen content in the topsoil and deeper soil showed significant variation among 9L, 9LB and 4LB plots (Table 3). The total nitrogen content of topsoil layer in 9LB plot was 28% and 14% higher than that in 9L plot and 4LB plot respectively and in the deeper soil 33% and 17% higher than that in 9L and 4LB plot respectively (Table 3).

The available nitrogen, phosphorus and potassium contents showed significant differences between 9LB plot and 9L plot for both topsoil and deeper soil. In 9LB plot available nitrogen, phosphorus and potassium contents were not higher than that in 4LB plot.

Photosynthesis

Based on the light-photosynthesis curves taken in August 1998 when all needles were mature (Figure 4), light saturated net photosynthetic rate (Psat) of larch in 9LB plot was 8.25 μmol m^{-2} s^{-1}, and was saturated at a higher PPFD (about 1000 μmol m^{-2} s^{-1}) than that in 9L plot. For trees in 9L plot, net photosynthetic rate was 7.2 μmol m^{-2} s^{-1} and was saturated at 500 μmol m^{-2} s^{-1}. However no difference was found in the apparent quantum yield between 9L and 9LB plots.

Values of accumulation of photosynthates in 9L and 9LB plots estimated on the basis of the date of photosynthetic and respiration rate of the whole day in August, 1998 showed in Table 4. Although the

Table 2. Soil density, soil porosity and soil water content at two soil layers among a nine-year-old pure larch forest (9L), a nine-year-old larch-soybean forest (9LB) and a four-year-old larch soybean forest (4LB).

Sample plot type	Soil density (g cm^{-3})		Soil porosity (%)		Soil water content (%)	
	0-15 cm	15-30 cm	0-15 cm	15-30cm	0-15 cm	15-30 cm
9L	1.20ab	1.25b	51.64ab	49.03ab	25.8b	31.1a
9LB	1.18a	1.23ab	52.61a	49.25ab	30.5ab	18.1b
4LB	1.19ab	1.22a	52.38a	50.30a	32.4a	19.3b

Values with the same letter (*a, b*) within a column are not significantly different from each other at $P<0.05$ (Least Squares Means using SAS analysis). All values are means of fifty replicates.

Table 3. Comparison of the soil nutrient condition at two soil depths among a nine-year-old pure larch forest (9L), a nine-year-old larch-soybean forest (9LB) and a four-year-old larch-soybean forest (4LB).

Sample plot type	Total N (%)		Available N (μg g^{-1})		Available P (μg g^{-1})		Available K (μg g^{-1})	
	Surface	20 cm	Surface	20 cm	Surface	20 cm	Surface	20 cm
9L	0.53bc	0.21c	65.36c	33.72c	17.35bc	10.67bc	189.6b	137.35bc
9LB	0.65a	0.28a	91.65a	46.83a	18.84a	11.33a	190.51a	139.94a
4LB	0.57b	0.24b	78.35b	38.90b	17.49b	10.86b	181.82bc	138.37ab

Values with the same letter (*a, b*) within a column are not significantly different from each other at $P<0.05$ (Least Squares Means using SAS analysis). All values are means of fifty replicates.

Table 4. Estimation of the accumulation of assimilation of larch in a nine-year-old pure larch forest (9L) and a nine-year-old larch-soybean forest (9LB).

Parameter	Sample plot types	
	9L	9LB
Net photosynthetic rate (μmol CO_2 $m^{-2}s^{-1}$)	7.20b	8.25a
Assimilation ratio per day (mg CO_2 $dm^{-2}d^{-1}$)	114.94b	130.20a
Gross assimilation per stand (m^2 $stand^{-1}$)	3.07b	17.81a
Accumulation of assimilation per day (g CO_2 d^{-1})	35.29b	231.88a
Photosynthetic yield (kg CO_2 d^{-1} ha^{-1})	116.46b	764.05a
Respiration rate (μmol CO_2 m^{-2} s^{-1})	2.28ab	2.71a
Consumption rate per day (mg CO_2 dm^{-2} d^{-1})	36b	42.8a

Values with the same letter (*a, b*) within a column are not significantly different from each other at $P<0.05$ (Least Squares Means using SAS analysis). All values are means of fifty replicates.

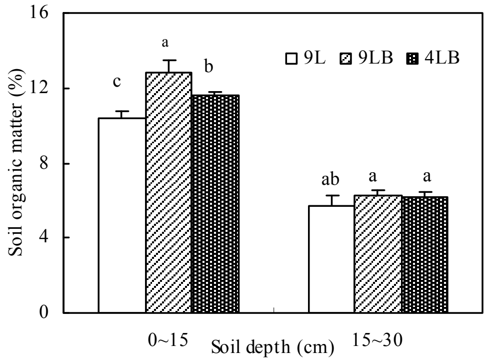

Fig. 2. The soil organic matter (%) contents in the topsoil (0-15 cm) and deeper soil (15-30 cm) among a nine-year-old pure larch forest (9L), a nine-year-old larch-soybean forest (9LB) plot and a four-year-old larch soybean forest (4LB).

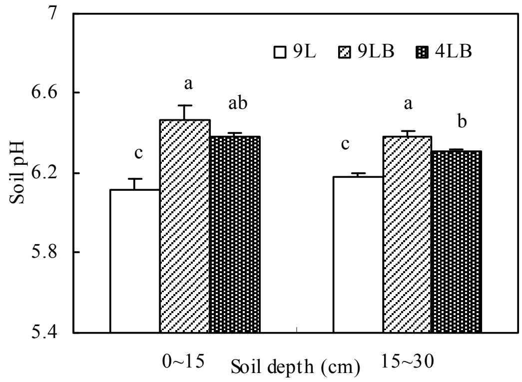

Fig. 3. The pH values in the topsoil (0-15 cm) and deeper soil(15-30 cm) among a nine-year-old pure larch forest (9L), a nine-year-old larch-soybean forest (9LB) and a four-year-old larch-soybean forest (4LB).

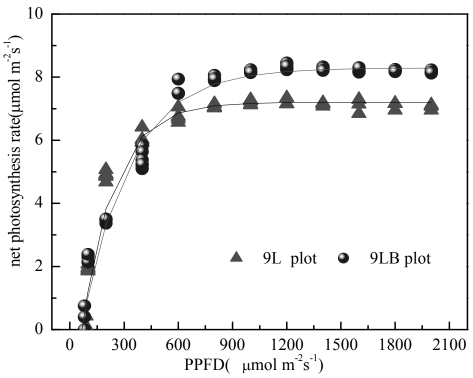

Fig. 4. A comparison the net photosynthetic rates of larch grown under a nine-year-old pure larch forest (9L) and a nine-year-old larch-soybean forest (9LB).

respiration rate and consumption rate per day were higher in 9LB plot than that in 9L plot, net photosynthetic rate, assimilation ratio per day, gross assimilation per stand, accumulation of assimilation per day and photosynthetic yield were significantly higher in 9LB plot than that in 9L plot.

Discussion

Analysis of height and diameter in Xingan larch plantation with different agro-forestry systems showed that tree growth was improved after soybeans were intercropped in the larch plantation.

Our results also clearly showed that the incorporation of soybean into Xingan larch plantation significantly improved soil physical and chemical properties, including reduction of soil bulk density and increase of soil organic matter. The reduction of soil bulk density in intercropping systems was observed by many studies (Agus *et al*. 1997, De Costa *et al*. 2005, Hulugalle and Kang 1990, Mapa and Gunasena 1995, Samsuzzaman *et al*. 1999). The increased activities of soil microorganisms in the soil profile of intercropping system have been proven to be beneficial for the soil structure and stability. Their activity is thought to help the soil particles form larger aggregates and thereby loosen the soil and decrease soil bulk density (Lawton 1994, Thevathasan and Gordon 2004).

Enhanced decomposition of soil organic matter i.e. release of nutrients from plants litter from activities of soil microbes has also been reported in other agro-forestry system (e.g. Hulugalle and Ndi 1994). The significantly higher soil organic matter in the topsoil layer improved the soil structure of larch-soybean intercropping system than the soil structure of pure larch plot.

It appears that larch-soybean intercropping has also increased nitrogen (N), phosphorus (P) and potassium (K) contents in the soil since nutrients added to the associated tree and crop. The higher soil N supply was possible through N input of rainfall and nitrogen fixation by symbiotic nodules of soybean. And tree-crop intercropping system may also increase deep soil N capture and reduce nutrient leaching. For phosphorus, the transformation process from more available inorganic P to readily available forms was promoted because of the increase of soil organic matter in tree-crop intercropping system.

Carbon sequestration was increased in active soil organic layer through litterfall, root turnover and incorporation of tree and crop residues. We summarized the accumulation of assimilation characteristics in table 4. Soybeans introduced into forest fields can enhance larch growth in the larch-soybean system. The net photosynthetic rate of larch in the larch-soybean system was higher than that in pure larch plot, and the increase was responsible for the increased carbon accumulation in the larch-soybean system in our study. Nitrogen supply increased by larch-soybean intercropping in soil influenced the photosynthesis of larch. The decreased soil bulk density and increased soil porosity and soil water content in the topsoil layer improved water uptake by root of larch in the larch-bean system. We also found that water use efficiency of larch in 9LB plot was about 122% of the value in 9L plot (data not shown). That may also be an important factor affecting the photosynthesis of larch. The duration of soybean's intercropping within a larch plantation seems to have an effect on larch growth in the 9LB and 4LB plots. The higher soil nutrient status of larch grown in 9LB plot compared to that in 4LB plot suggested that larch-soybean system would be more beneficial to larch growth as the duration of intercropping increased.

There also exists a potential competition between larch and soybean in the intercropping system as they share resources such as light, water and nutrients. However, we didn't find evidence for any negative effects of competition on larch growth when we compared result between the 9LB and the 9L plot. It may be possible that the positive effects of the intercropping were much higher than its negative effects on larch growth. Moreover, the activities of the symbiotic nodules usually increase soil fertility. Therefore, we may expect the positive effects of incorporating of soybeans to improve larch growth for relatively short period after soybean introduction.

Thus, we conclude that the larch-soybean intercropping system has the potential to increase soil nutrients in the early stage of soybean introduction in Xingan larch plantations. Results and conclusions of the study will be invaluable to the management of larch plantation in the future.

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