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Photosynthesis and Net Assimilation Rate in two-year-old Seedlings of *Pinus rigida* and *Pinus rigida* x *P. taeda* F_1[1]

Yang Youn[2] · Don Koo Lee[3] · Sang Yung Shim[2]

리기다소나무와 리기테다소나무 苗木의 光合成能力과 純同化率 比較 硏究[1]

尹 陽[2] · 李 敦 求[3] · 沈 相 榮[2]

ABSTRACT

Photosynthetic ability and net assimilation rate were compared between two-year-old seedlings of *Pinus rigida* and of *Pinus rigida* x *P. taeda* F_1 to examine whether growth potential could be predicted at young stages. Six families per each species used in this study were grown at the nursery of the Institute of Forest Genetics in Suweon. Photosynthesis and net assimilation rate showed seasonal and genetic variations among the families. Photosynthetic ability of most of the families except for three families of *Pinus rigida* decreased with increasing ages, while net assimilation rate of all the families decreased with increasing ages. The rank of photosynthetic ability and net assimilation rate among the families varied during the experimental period. Thus, growth potential was better predicted from total photosynthetic ability and total net assimilation rate rather than from photosynthetic ability and net assimilation rate at a certain period. Total photosynthetic ability and total net assimilation rate were correlated with total dry weight. Correlation coefficients were 0.6394 and 0.7998, respectively. Thus, growth potential of the two species could be predicted by the measurement of total photosynthetic ability and total net assimilation rate. Family K.G. No. 13x7-107 from *Pinus rigida* x *P. taeda* F_1 and family K.G. No. 1 from *Pinus rigida* were the best in total photosynthetic ability and total net assimilation rate within species.

Key words: photosynthesis; net assimilation rate; Pinus rigida; Pinus rigida × P. taeda.

要 約

리기다소나무와 리기테다소나무의 幼時 및 家系間의 生長能力을 豫測하기 위하여 2年生 苗木을 對象으로 生長, 光合成能力 그리고 純同化率을 調査 比較하였다. 리기다소나무와 리기테다소나무 모두 純同化率과 光合成能力의 遺傳的 變異를 볼 수 있었으며, 리기다소나무 3家系를 제외한 다른 모든 家系의 光合成能力은 生長함에 따라 減少하는 傾向을 보였으며 純同化率은 모든 家系가 減少하였다. 모든 家系의 光合成能力과 純同化率의 순서가 實驗期間 동안 일정하지 않아 어느 한 時期의 測定値로 評價할 수 없으므로 總光合成 能力

[1] 接受 2月 15日 Received February 15, 1984.
[2] 林木育種硏究所 Institute of Forest Genetics, Suweon, Korea.
[3] 서울大學校 農科大學 College of Agriculture, Seoul National Univ., Suweon, Korea.

과 總純同化率로 評價하였다. 總光合成能力과 總純同化率은 總乾重量과 各各 0.6394, 0.7998의 相關을 나타냈다. 따라서, 兩樹種의 生長力은 總光合成能力과 總純同化率의 測定에 의해 豫測할 수 있었다. 리기테다소나무의 家系 京畿 13號×7－107과 리기다소나무의 家系 京畿1號가 樹種內에서 가장 우수한 生長能力을 나타냈다.

INTRODUCTION

Growth or dry matter production results mainly from photosynthetic fixation of carbon dioxide and only a small fraction of total dry matter in plants is represented by mineral elements. Therefore, if the amount of total CO_2 assimilation could be measured for longer period, it could be directly related to accumulation of dry matter. Many foresters and agronomists have suggested the rate of CO_2 uptake as a variable for measuring genetic differences in growth[1,7,14,21] and have demonstrated genetic variation in the rate of photosynthetic and respiratory CO_2 exchange among species, provenances, families, or clones of trees.[2,4,6,8,9,13,14,15,18,22,26,28,33]

One of the most needed innovations in tree breeding is a technique for predicting the breeding value of species, provenances, strains, or families based on juvenile evaluation of their progenies. Accordingly, photosynthetic ability or assimilation rate was compared at early growth stages and often correlated to growth variables.

However, photosynthetic or assimilation rate bears no correlation to, or even negative correlation to, seedling "growth" as measured by top dry weight. Even an imperfect correlation might increase genetic gain if the selection cycle could be sufficiently shortened.

Photosynthesis or net assimilation rate cannot be characterized by measurements at only one period in the growing season. Seasonal changes of net photosynthesis have been widely reported for a variety of plant species, such as *Pinus taeda*,[6,20,29] *Larix* and *Platanus*,[14] *Pinus strobus*,[30] *Pinus densiflora*,[22] *Picea* and *Tsuga*,[2] *Eucalyptus*,[27] and *Artemisia*.[5]

Growth analysis is a technique which separates growth into component processes to study the effect of endogenous and exogenous influences. It is also a dynamic or simple method focusing on rates of growth rather than on final yields. Growth analysis utilizes measurements of dry weight and leaf area obtained from periodic harvests to partition growth among component characteristics without elaborate instrumentation or facilities. One of the most important growth characteristics, describing the net production efficiency of the assimilatory apparatus, is net assimilation rate (NAR).[3,31] The parameters estimated by growth analysis can be used to compare the effect between various treatments, varieties, or progenies. Because of the obvious difficulties in harvesting and weighing large trees, classical growth analysis was not applied to forest species until relatively recent period, and only to seedling stages.[13,16,23,25] Thus, two-year-old seedlings were used for growth analysis in this study.

The objective of this study was to predict growth potential (1) by comparing photosynthetic ability, net assimilation rate between *Pinus rigida* and *Pinus rigida* x *P. taeda* F_1 seedlings and between families within species, and (2) by examining seasonal variation in net assimilation rate and its relation to growth.

MATERIALS AND METHODS

Seedlings of two-year-old *Pinus rigida* and *Pinus rigida* x *P. taeda* F_1 were provided as plant materials. Six families of *Pinus rigida* were pollinated with five different sources of *Pinus taeda* pollens at the Interior Breeding Station Clone Bank at Chung Ju in early May of 1980. Two sources of pollens came from Kwang Ju and Kwang Yang plantations in Korea and three sources (7-17, 7-59 and 7-107) were introduced from South Carolina, U.S.A..

Pollens of Kwang Yang plantations were collected from several trees, while the others were collected from individual trees. *Pinus rigida* x *P. taeda* F_1 seeds as well as open pollinated seeds were collected in mid-September of 1981. Seeds were stratified with damp peat for 30 days, and then sown at the end of March of 1982 at the nursery of the Institute of Forest Genetics, Suweon. Seedlings of *Pinus rigida* x *P. taeda* F_1 were covered with polyethylene film for protecting from winter frost damage. In following spring, the seedlings selected for uniformity were transplanted at a spacing of 15cm by 20cm.

A randomized block design with three replicates was adopted. Twelve families (6 families per species) were randomly allocated to each block. Each family consisted of ten seedlings per block. During the dry period, the nursery was watered every other day.

Seedlings were harvested five times during the period of June 20 through September 12 to measure dry weights. Then, seedlings were divided into three parts: needles, stems and roots for measurements. Roots were washed to remove soil particles before measurements. Most of the seedlings were mycorrhized. Dry weights of each part were determined after drying for 72 hours at 80°C.

Photosynthetic ability was measured with Oxygen Electrode and Meter (YSI. Co. Ohio, U.S.A.) 4 times during the growing season excluding July 11th. Measurement procedure described by Kim and Lee (1983)[10] was used for this study. Because of seasonal variations in the photosynthesis rank among the families, the total photosynthetic ability was calculated from the integral of the curve areas over the entire periods.

Net assimilation rate (NAR) and relative growth rate (RGR) were also calculated by using the method of Radford (1967)[24] as follows:

$$NAR = (W_2 - W_1)(\ln LW_2 - \ln LW_1) / (LW_2 - LW_1)(t_2 - t_1)$$

$$RGR = (\ln W_2 - \ln W_1)/(t_2 - t_1)$$

where W_1 = total dry weight at the beginning of each period

W_2 = total dry weight at the end of each period

LW_1 = leaf dry weight at the beginning of each period

LW_2 = leaf dry weight at the end of each period

$t_2 - t_1$ = length of the sampling intervals as weeks

RESULTS

Photosynthetic ability

The seasonal changes of mean photosynthetic ability of seedlings for the two species are presented in Figure 1. The photosynthetic ability of the two species remarkably declined as trees grow. The ability in September showed only 34 percent of that in June. There were no significant differences

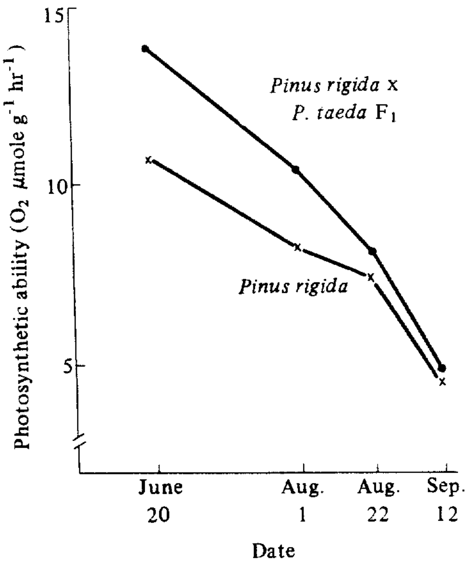

Fig. 1. Seasonal changes in mean photosynthetic ability of *Pinus rigida* and *Pinus rigida* x *P. taeda* F_1.

between the two species. However, *Pinus rigida* x *P. taeda* F_1 was superior to *Pinus rigida* during the growing season. The largest difference between the two species in photosynthetic ability was found on June 20th. As the seedlings grow, the difference became smaller. On September 12th when the final measurement was made, the photosynthetic ability was almost same between the two species. In contrast, the amount of respiration was similar between the two species during the growing season.

The variation in photosynthetic ability among families of *Pinus rigida* and *Pinus rigida* x *P. taeda* F_1 is shown in Figure 2 and 3. In general, the photosynthetic ability of all the families decreased as seedlings grow except for three families of *Pinus rigida*. They showed rather an increase in the ability on August 22nd compared to that on August 1st. The rank in photosynthetic ability was significantly different among families at the 5% level. Most of *Pinus rigida* x *P. taeda* F_1 families showed greater photosynthetic ability than *Pinus rigida* families (Table 1).

High total photosynthetic abilities were shown by *Pinus rigida* x *P. taeda* F_1 families K.G. No. 8x7-107, K.G. No. 9xK.J. and K.G. No. 13x7-107, whereas low abilities were shown by *Pinus rigida* families K.G. No. 9, 8 and 13.

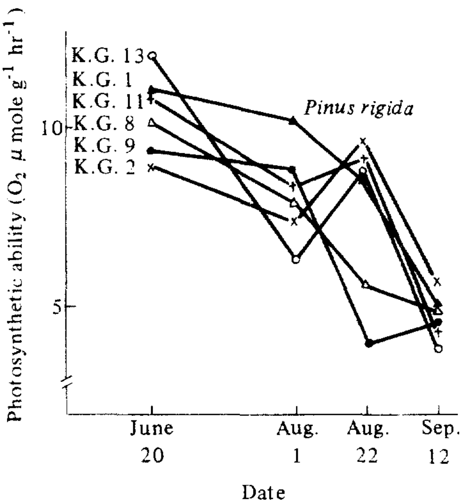

Fig. 2. Seasonal changes in photosynthetic ability of *Pinus rigida* seedlings.

The correlation coefficient (r=0.6394) between total photosynthetic ability and total dry weight was significant at the 5% level (Figure 4).

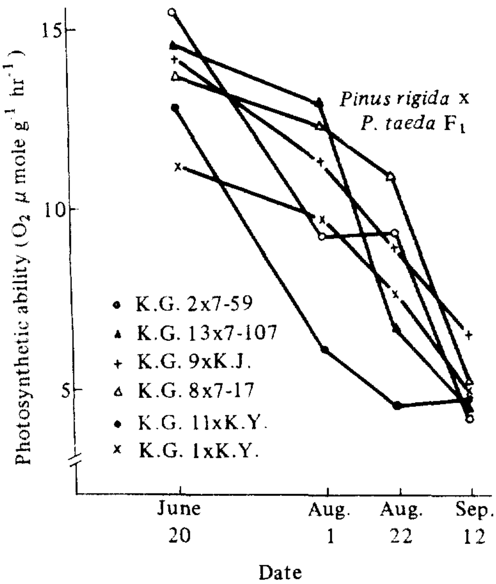

Fig. 3. Seasonal changes in photosynthetic ability of *Pinus rigida* x *P. taeda* F_1 seedlings.

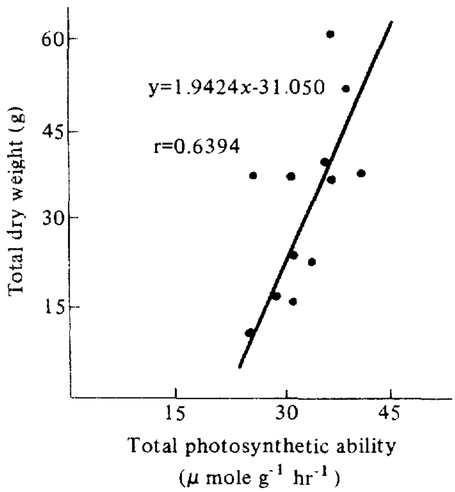

Fig. 4. Relation between mean total dry weight and total photosynthetic ability for two species.

Net assimilation rate and relative growth rate

The seasonal changes in mean net assimilation rate of the two species were shown in Figure 5. The mean net assimilation rate of the two species decreased with increasing ages, which was similar to the trend of photosynthetic ability. *Pinus rigida* showed a steeper decreasing trend than *Pinus rigida* x *P. taeda* F_1. No significant correlation was found between individual NAR and photosynthetic ability. The NAR of *Pinus rigida* x *P. taeda* F_1 was higher than that of *Pinus rigida* during the growing season. Greater total dry weight was also produced

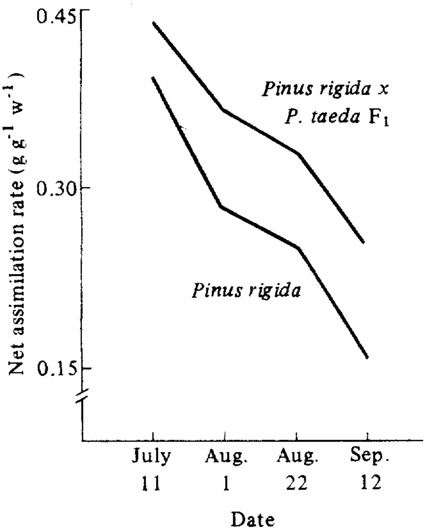

Fig. 5. Seasonal changes in mean net assimilation rate of *Pinus rigida* and *Pinus rigida* x *P. taeda* F_1.

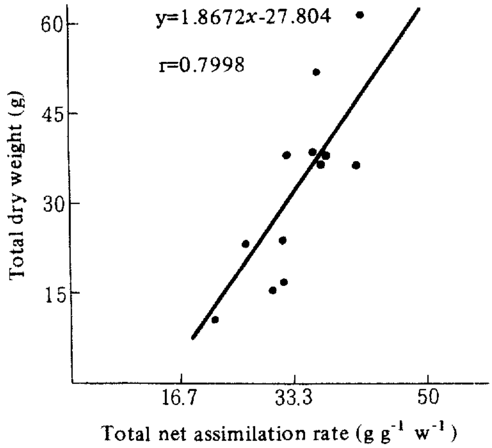

Fig. 6. Relation between mean total dry weight and total net assimilation rate for two species.

by *Pinus rigida* x *P. taeda* F_1 than by *Pinus rigida* (Table 1).

Table 2 shows the variation in NAR o two species. The NAR of all the families decreased with increasing ages. Differences in total NAR calculated from the areas of NAR curve were significant among families at the 5% level (Table 1). Family K.G. No. 13x7-107 was the highest among all the families and family K.G. No. 9 the lowest. The correlation coefficient (0.7998) between the integraled area under the NAR curve during the growing season and total dry weight was highly significant (Figure 4). The decreasing trend of relative growth rate with increasing dates was similar to that of NAR (Table 3).

Table 1. Total photosynthetic ability, total dry weight and total net assimilation rate of families by species.

Species	Family	Total photosynthetic ability(μ moleg^{-1} hr^{-1})	Total dry weight (g)	Total net assimilation rate (gg^{-1} w^{-1})
Pinus rigida	K.G. No. 1[a]	33.9	24.0	30.1
	K.G. No. 2	30.8	16.5	29.4
	K.G. No. 8	25.4	36.6	35.3
	K.G. No. 9	25.2	12.2	20.7
	K.G. No. 11	31.7	24.3	25.2
	K.G. No. 13	29.0	16.6	28.8
	mean	29.3	21.7	28.3
Pinus rigida x *P. taeda* F_1	K.G. No. 1 x K.Y.[b]	35.6	39.4	31.8
	K.G. No. 2 x 7-59	35.7	35.2	41.7
	K.G. No. 8 x 7-17	40.5	39.6	33.2
	K.G. No. 9 x K.J.[c]	38.5	51.3	34.8
	K.G. No. 11 x K.Y.	31.5	36.1	35.3
	K.G. No. 13 x 7-107	36.1	60.7	42.6
	mean	36.3	43.7	36.6

a : Kyung Gi No. 1 selected as plus tree of *Pinus rigida*.

b : Kyung Gi No. 1 selected as plus tree of *Pinus rigida* was pollinated with *Pinus taeda* pollens from Kwang Yang plantations.

c : Kwang Ju.

Table 2. Net assimilation rate of *Pinus rigida* and *Pinus rigida* x *P. taeda* F1 seedlings.

Species	Family	Net assimilation rate ($gg^{-1}w^{-1}$)			
		July 11	Aug. 1	Aug. 22	Sep. 12
Pinus rigida	K.G. No. 1	0.4031	0.3302	0.2654	0.1358
	K.G. No. 2	0.4801	0.2431	0.2429	0.1586
	K.G. No. 8	0.4709	0.3338	0.3241	0.2392
	K.G. No. 9	0.2643	0.2309	0.1815	0.1027
	K.G. No. 11	0.3420	0.2668	0.2150	0.1471
	K.G. No. 13	0.4177	0.3326	0.2838	0.1609
	mean	0.3964	0.2896	0.2521	0.1574
Pinus rigida x *P. taeda* F1	K.G. No. 1 x K.Y.	0.3911	0.3105	0.2881	0.2445
	K.G. No. 2 x 7-59	0.4370	0.4340	0.3872	0.3225
	K.G. No. 8 x 7-17	0.3996	0.3730	0.2755	0.2090
	K.G. No. 9 x K.J.	0.3939	0.3486	0.3047	0.3013
	K.G. No. 11 x K.Y.	0.4809	0.3341	0.3339	0.2117
	K.G. No. 13 x 7-107	0.5205	0.4288	0.4207	0.2327
	mean	0.4372	0.3715	0.3354	0.2536

Table 3. Relative growth rate of *Pinus rigida* and *Pinus rigida* x *P. taeda* F1 seedlings during the growing season.

Species	Family	Relative growth rate (gw^{-1})			
		July 11	Aug. 1	Aug. 22	Sep. 12
Pinus rigida	K.G. No. 1	0.2310	0.1812	.0.1440	0.0761
	K.G. No. 2	0.1906	0.1242	0.1200	0.0820
	K.G. No. 8	0.2584	0.1806	0.1689	0.1218
	K.G. No. 9	0.1420	0.1282	0.1020	0.0637
	K.G. No. 11	0.1967	0.1547	0.1214	0.0820
	K.G. No. 13	0.2243	0.1716	0.1484	0.0867
	mean	0.2072	0.1568	0.1341	0.0854
Pinus rigida x *P. taeda* F1	K.G. No. 1 x K.Y.	0.2049	0.1634	0.1618	0.1386
	K.G. No. 2 x 7-59	0.2310	0.2341	0.2122	0.1786
	K.G. No. 8 x 7-17	0.2136	0.2030	0.1596	0.1203
	K.G. No. 9 x K.J.	0.2036	0.1888	0.1753	0.1647
	K.G. No. 11 x K.Y.	0.2693	0.1860	0.1856	0.1185
	K.G. No. 13 x 7-107	0.2611	0.2133	0.2155	0.1228
	K.G. mean 13 x 7-107	0.2306	0.1981	0.1850	0.1406

Total dry weight was significantly different among families at the 5% level (Table 1). Families K.G. No. 13 x 7-107 and K.G. No. 9xK.J. showed remarkably higher total dry weight per seedling than the other families. These two families grew better vigorously than the other families during the growing season. Generally, *Pinus rigida* x *P. taeda* F_1 produced more total dry weight than *Pinus rigida*.

DISCUSSION

Dry matter accumulation expressed as the amount of growth results mainly from photosynthesis and respiration. A significant correlation (r= 0.6394) between total photosynthetic ability and total dry weight was similar to that reported by other researchers.[8,9,19] From the provenance study of Logan (1971)[17] on 7-year-old jack pine, a good correlation (r=0.85) was found between tree height and photosynthetic rate measured in October, while no correlation was found in other months. Therefore, differences in the seasonal changes of assimilation should be considered in selecting superior families. A plant with higher rate of photosynthesis at one stage may have lower rate at another stage. Photosynthetic ability and NAR decreased with increasing ages in this experiment. This may be a general characteristics for conifers,[2,6,16,28] which is probably ascribed to (1) increased self-shading of needles as the total needle area increases,[12] (2) decreasing photosynthetic efficiency in the ontogenetic leaves produced as cotyledon, primary and secondary needles,[32] (3) increased diffusion resistance resulted from accumulation of wax in stomatal pores,[15] or (4) increased respiration as a result of increasing amounts of stem tissue. Considering the fact that all materials used in this study were only the secondary needles, probably all but the above (2) caused the decreased photosynthetic ability and NAR in this study.

Higher NAR of *Pinus rigida* x *P. taeda* F_1 than that of *Pinus rigida* in this study may be explained that *Pinus rigida* x *P. taeda* F_1 grows rapidly and longer compared to *Pinus rigida*. Accordingly, *Pinus rigida* x *P. taeda* F_1 is apt to be damaged by cold. Total photosynthetic ability per unit weight was not significantly different between the two species. However, *Pinus rigida* x *P. taeda* F_1 was greater in total photosynthetic ability on a seedling basis than *Pinus rigida* because *Pinus rigida* x *P. taeda* F_1 had greater amounts of needles per seedling. The results that there was no difference in total photosynthetic ability on a unit weight basis between the two species was similar to those reported by Kim (1976)[11] who observed no differences in photosynthetic ability between 6-to-8-year-old *Pinus rigida* x *P. taeda* F_1 and *Pinus rigida*. He mentioned that the reason for high productivity in *Pinus rigida* x *P. taeda* F_1 was due to its longer photosynthesis of needles, less respiration of needles, greater amounts of needle per tree, and more effective light acceptance than *Pinus rigida*.

If, at every stage of growth, the amount of photosynthetic surface was equal among families, then areas under the NAR curve should bear a one-to-one relationship to cumulative growth.[16] Thus, total NAR cumulation were calculated. Considering the high correlation (r=0.7998) between total NAR cumulation and total dry weight in this study, 64 percent of the variation in dry weight per seedling could be accounted for by cumulation NAR. Thus, the cumulative NAR could be used for the prediction of total dry weight. As most of the families of both *Pinus rigida* x *P. taeda* F_1 and *Pinus rigida* show variations in NAR, early selection of genetically superior trees in rapid growth might be possible. However, further work is required to determine whether such selection is applicable to larger trees.

CONCLUSION

Photosynthetic ability and growth parameters such as net assimilation rate, relative growth rate examined between *Pinus rigida* and *Pinus rigida* x *P. taeda* F_1 seedlings to select superior families at early growing stages.

Mean photosynthetic ability was not significantly different between the two species. Total photosynthetic ability was significantly different among families at the 5% level. Photosynthetic ability of most of the families of *Pinus rigida* declined with increasing seedling size. The correlation coefficient (r=0.6394) between total photosynthetic ability and total dry weight was significant at the 5% level.

Net assimilation rate of all the families decreased with increasing ages during the experimental period. Differences in net assimilation rate were significant among families at the 5% level. The correlation coefficient (r=0.7998) between total cumulative net assimilation rate and total dry weight was highly significant.

Considering photosynthetic ability and net assimilation rate, families K.G. No. 13 x 7-107, K.G. No. 9 x K.J., K.G. No. 2 x 7-59 and K.G. No. 8 x 7-17 from *Pinus rigida* x *P. taeda* F_1 and family K.G. No. 1 from *Pinus rigida* were the best in growth potential among the families.

Thus, it was concluded that photosynthetic ability and net assimilation rate could be used to predict the growth potential of *Pinus rigida* and

Pinus rigida x *P. taeda* F_1 seedlings.

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