FERTILITY STANDARDS FOR GROWTH OF CRYPTOMERIA SEEDLINGS BASED ON A STUDY OF FOREST AND NURSERY SOILS

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INTRODUCTION

Cryptomeria (*Cryptomeria japonica* D. Don) has been introduced from Japan and nowadays it is a major species in the coniferous forests elevated between 800 and 2,200 meters in Taiwan. It is economically important, especially as a very useful timber for house construction, bridges, etc. Numerous seedlings of Cryptomeria are annually planted on reforested lands or to replace hardwood forests. Better forests always result from healthy seedlings. In recent years foresters in Taiwan have worked on the problem of quality improvement of seedlings in the nursery. The maintenance of fertility in nursery soil at an adequate level for the growth of seedlings is one of the ways to improve nursery stock quality. Unfortunately little is known about the fertility standards for growing this species in the nursery, and foresters concerned with securing a rapid growth of healthy seedlings are handicapped by this lack of information. The importance of fertility standards for growing tree species in nurseries has been pointed out by Wilde (12), Widle and Patzer (14), and Youngberg and Austin (15). The nursery stock may possess a high survival potential when they grow with adequate fertility in nursery soil.

In order to establish fertility standards for growing China fir seedlings in nurseries, the fertility of China fir forest and nursery soils were studied previously (1) by means of soil and foliar analyses as well as fertilizer tests. In the present study the same methods are followed for the purpose of establishment of fertility standards for raising Cryptomeria seedlings in nurseries.

METHODS

The present study is separated into four sections, (a) soil analysis for various factors concerned with the fertility in both Cryptomeria forest and nursery soils, (b) foliar analysis for various nutrients in both Cryptomeria tree needles and nursery seedling needles, (c) fertilizer tests, and (d) fertility standards for growth of Cryptomeria seedlings.

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Fifty four soil samples were collected from the Cryptomeria forests and eight were sampled from the nurseries supporting Cryptomeria seedlings. Soil was taken from 0-6″, air dried, and then sieved through a 2 mm. screen. Foliage was also collected at the time of each soil sampling. According to the suggestions by Leyton and Armson (5), and Gessel (2), the current years' foliage was sampled from the uppermost shoot of a Cryptomeria tree grown at the place from which the soil sample was collected. The ages of the trees were between five and twenty years after planting in the field; the foliage sampling was done in September 1959.

Soils for fertilizer tests were separately collected from the Cryptomeria forests at Chuyunshan. Pot cultures with Cryptomeria seedlings were mede out of doors at Tatushan. Six-inch pots were used, with three seedlings per pot in quadruplicate. In these tests 2,000 grams of soil were weighed into a pot and then fertilized with various treatments as shown in Tables 8 and 11. The designation N_1, P_1, and K_1 indicate that the soil received nitrogen fertilizer at the rate of 100 pounds per acre, 100 pounds P_2O_5 per acre, and 100 pounds K_2O per acre, respectively. The calcium was added at the rate of 2,000 pounds $CaCO_3$ per acre, and the magnesium, at the rate of 20 pounds Mg per acre. The Cryptomeria seedlings at about 4 cm. height were transplanted in the pots on June 27, 1960, and they were harvested on December 25, 1960. During the growing period the seedlings were watered with distilled water once a day depending upon the moisture condition of the soils. At the time of harvest the seedlings were individually separated at the ground line, and the needles from each treatment in guadruplicate were thoroughly mixed for chemical analysis.

The foliage tissues collected from the field, the nurseries and pot cultures were dried to a constand weight in an oven at 70°C. The needles were ground in a Wiley mill through a 40 mesh screen, and they were analysed for nitrogen, phosphorus, potassium, calcium, and magnesium.

Total nitrogen was determined by the Kjeldahl method modified from Winkler (8); the ammonia was distilled into boric acid solution and then titrated with standard hydrochloric acid solution. The samples of plant tissue used for phosphorus, potassium, calcium and magnesium determinations were prepared by the usual dry ashing method. Magnesium and phosphorus were determined by a modification of the molybdi-vanadate method of Murray and Ashley (6). Magnesium was precipitated as magnesium ammonium phosphate and then estimated by comparing with phosphate standards on a colorimeter; for phosphate the ash solution was used directly. Potassium was precipitated as the cobaltinitrite and titrated with standard permanganate (3); calcium was precipitated as calcium oxalate, and the oxalate titrated with permanganate in hot sulfuric acid solution (4).

The soil was analysed for soil reaction, organic matter, total nitrogen, available phosphorus, cation exchange capacity, and exchangeable potassium, calcium and magnesium. Soil reaction was measured by glass electrode with a soil-water ratio of 1:1 (8). Organic matter of the soil was determined by the potassium dichromate method (8). Total nitrogen was determined as described above for plant tissue. Available phosphorus was extracted with dilute sulfuric acid (11) and then estimated by comparing with phosphorus standards on a colorimeter. Cation exchange capacity was determined by a method modified from Peech et al. (7). The leachate was evaporated to dryness, treated with concentrated nitric acid and hydrochloric acid, and dried again. The residue was then heated at 390°C., cooled and dissolved with 0.1 N HNO_3, and subjected to the same method used in analysis of the plant tissue for potassium, calcium and magnesium elements.

RESULTS AND DISCUSSION

1. Soil fertility.

Tables 1 and 2 present the chemical composition of Cryptomeria forest soils and of Cryptomeria nursery soils, respectively. Soil fertility varies greatly with different kinds of soil. Table 3 shows the arithmetic means of the chemical composition of Cryptomeria forest and nursery soils.

The mean for the concentration of exchangeable magnesium in the forest soils is higher with statistical significance than that of the nursery soils (Table 3). Although the means for the contents of soil reaction, organic matter, total nitrogen, available phosphorus, cation exchange capacity, and exchangeable potassium and calcium in the Cryptomeria forest soils are greater than those of the nursery soils, the differences are not significant.

Table 1

Chemical composition of the Cryptomeria forest soils and tree needles

Sample No.	Chemical composition of the Cryptomeria forest soils										Chemical composition of the needles of Cryptomeria tree					Sampling location	
	pH	O.M. (%)	Total N (%)	C/N ratio	Avail. P (%)	Avail. P lb./A.	Exc. K (m.e.)	Exc. Ca (m.e.)	Exc. Mg (m.e.)	C.E.C. (m.e.)	N (%)	P (%)	K (m.e.)	Ca (m.e.)	Mg (m.e.)	Location	Elevation (m.)
1	4.82	8.37	0.40	9.1	0.00271	54.2	0.352	0.65	0.49	35.2	2.41	0.207	27.0	24.3	24.7	Tayenshan	1400
2	4.92	7.67	0.38	8.8	0.00102	20.4	0.468	0.58	0.53	26.7	2.13	0.228	21.6	12.3	21.3	Tayenshan	1100
3	6.10	3.32	0.26	5.6	0.01624	324.9	0.136	4.22	0.96	7.5	1.50	0.276	28.6	34.4	17.7	Kulu, Rotung	—
4	6.20	7.18	0.35	8.9	0.00528	105.7	0.446	5.93	1.62	19.3	1.98	0.378	19.3	28.7	24.2	Tayenshan	900
5	4.60	12.72	0.74	7.5	0.00160	32.0	0.354	1.07	0.69	39.1	1.94	0.261	19.2	23.3	20.4	Tayenshan	950
6	5.80	12.92	0.68	8.3	0.00135	27.1	0.722	2.48	1.52	34.4	1.82	0.228	20.4	23.5	16.8	Tayenshan	1000
7	5.10	14.87	0.95	6.8	0.00322	64.4	0.478	4.23	1.90	47.6	1.85	0.235	27.2	17.7	18.1	Tayenshan	1000
8	5.80	9.99	0.49	8.9	0.00175	35.0	0.193	1.73	0.26	28.1	1.72	0.259	19.6	24.6	23.0	Ayu, Wenshan	340
9	5.25	4.79	0.26	8.0	0.00136	27.2	0.347	0.47	0.84	19.0	1.66	0.281	33.9	22.5	21.7	Ayu, Wenshan	300
10	5.90	4.67	0.26	7.8	0.00119	23.7	0.506	3.36	1.33	18.7	1.97	0.314	38.2	25.2	20.4	Ayu, Wenshan	280
11	5.30	5.07	0.19	11.6	0.00186	37.2	0.251	4.73	1.29	18.6	1.84	0.344	48.6	17.1	17.7	Ayu, Wenshan	340
12	4.90	6.26	0.26	10.5	0.00214	42.9	0.351	2.17	1.05	23.0	1.77	0.314	44.1	24.4	21.7	Ayu, Wenshan	340
13	4.70	7.29	0.31	10.2	0.00052	10.4	0.185	0.20	0.52	22.1	1.87	0.245	38.5	18.2	30.5	Ayu, Wenshan	330
14	5.20	10.90	0.55	8.6	0.00289	57.9	0.632	6.70	2.67	37.5	1.61	0.190	13.3	34.5	25.1	Ayu, Wenshan	520
15	4.70	7.03	0.37	8.3	0.00153	30.5	0.223	0.41	0.61	27.0	1.77	0.163	22.1	57.3	17.3	Ayu, Wenshan	480
16	5.85	5.24	0.33	6.9	0.00256	51.1	0.613	6.28	1.59	20.3	2.40	0.210	37.9	42.3	30.3	Ayu, Wenshan	340
17	5.15	6.68	0.36	7.4	0.00087	17.4	0.287	1.19	0.92	26.7	1.82	0.171	34.0	35.7	24.2	Ayu, Wenshan	340
18	4.30	13.99	0.58	10.5	0.00176	35.2	0.359	7.07	1.62	41.8	1.72	0.163	21.3	23.4	17.7	Huayuan, Chutung	930
19	7.20	10.73	0.55	8.5	0.00910	182.0	0.415	19.64	6.47	30.6	1.76	0.269	31.0	33.5	32.4	Chingchuan, Chutung	760
20	7.00	2.72	0.12	9.9	0.01383	276.6	0.430	8.13	1.10	19.9	2.03	0.341	31.3	30.4	30.5	Chingchuan, Chutung	570

Table 1 (Cont.)

Chemical composition of the Cryptomeria forest soils and tree needles

Sample No.	Chemical composition of the Cryptomeria forest soils: pH	O.M. (%)	Total N (%)	C/N ratio	Avail. P (%)	Avail. P lb./A.	Exc. K (m.e.)	Exc. Ca (m.e.)	Exc.Mg (m.e.)	C.E.C. (m.e.)	Chemical composition of the needles of Cryptomeria tree: N (%)	P (%)	K (m.e.)	Ca (m.e.)	Mg (m.e.)	Sampling location: Location	Elevation (m.)
21	6.80	4.22	0.24	7.6	0.00831	166.2	1.372	12.49	4.47	21.2	2.21	0.406	49.6	20.3	21.9	Chingchuan, Chutung	570
22	5.05	6.70	0.23	12.7	0.00083	17.0	0.215	1.40	0.50	12.9	1.76	0.218	32.7	15.8	19.4	Chiapaotai, Pahsienshan	880
23	4.90	7.39	0.26	11.5	0.00483	96.5	0.356	0.95	0.42	14.8	2.20	0.310	48.0	26.5	17.7	Chiapaotai, Pahsienshan	910
24	4.95	8.65	0.42	9.0	0.00173	34.5	0.255	2.10	0.76	27.7	2.23	0.259	35.8	30.2	33.4	Chiapaotai, Pahsienshan	1050
25	6.25	10.04	0.45	9.7	0.00223	44.6	0.222	17.88	1.95	29.0	1.59	0.225	26.7	29.3	23.9	Chiapaotai, Pahsienshan	980
26	7.60	8.22	0.27	13.2	0.01119	223.7	0.348	14.54	4.12	21.9	1.69	0.214	26.0	23.0	28.2	Malun, Pahsienshan	2250
27	5.45	9.51	0.40	10.3	0.00056	11.1	0.213	0.37	2.86	38.5	2.92	0.292	25.0	33.5	34.5	Malun, Pahsienshan	2250
28	4.92	8.96	0.35	11.1	0.00027	4.9	0.416	1.59	0.56	38.9	1.89	0.243	30.1	19.8	15.6	Malun, Pahsienshan	2250
29	4.55	7.96	0.32	10.8	0.00145	28.9	0.551	3.68	1.09	21.9	1.85	0.159	26.2	18.7	15.4	Malun, Pahsienshan	2250
30	5.70	6.43	0.24	11.7	0.00042	8.5	0.569	1.79	0.67	26.1	2.93	0.379	48.4	18.5	22.8	Malun, Pahsienshan	2250
31	4.70	7.46	0.28	11.6	0.00085	17.1	0.268	0.20	0.25	21.4	0.91	0.063	33.2	35.3	15.2	Malun, Pahsienshan	2250
32	4.55	11.13	0.43	11.3	0.00668	123.6	0.353	20.41	0.81	36.4	2.86	0.426	67.3	16.0	17.3	Sinshan, Pahsienshan	2150
33	5.30	4.24	0.14	13.2	0.00034	6.7	0.696	0.73	0.42	15.6	1.43	0.137	36.5	23.2	23.4	Sinshan, Pahsienshan	2200
34	4.70	11.43	0.49	9.7	0.00107	21.5	0.242	0.60	0.14	35.2	1.81	0.163	37.9	30.9	13.7	Shihwenhsi, Pahsienshan	2250
35	4.73	9.33	0.43	9.4	0.00021	4.2	0.260	0.49	0.29	41.8	1.53	0.124	29.0	26.3	20.8	Shihwenhsi, Pahsienshan	2250
36	4.18	12.12	0.39	13.5	0.00156	31.2	0.227	0.27	0.31	23.3	0.73	0.131	27.5	42.5	11.2	Sinshan, Pahsienshan	2300
37	4.25	8.85	0.27	14.3	0.00152	30.5	0.341	0.94	0.69	16.6	1.63	0.181	20.0	29.3	23.2	Sinshan, Pahsienshan	2230
38	4.99	8.42	0.37	9.9	0.00051	10.2	0.293	2.50	0.30	20.8	2.80	0.308	26.8	22.1	24.2	Arishan	2100
39	5.75	16.74	0.73	10.0	0.01041	208.1	0.592	19.56	0.86	36.3	1.79	0.247	31.5	31.7	9.1	Arishan	2200
40	4.00	10.90	0.49	9.7	0.00276	55.2	0.342	0.20	0.63	17.8	1.95	0.193	17.8	34.5	11.8	Arishan	2200
41	4.60	10.35	0.49	9.2	0.00104	20.8	0.251	0.69	0.52	20.3	1.92	0.155	25.8	43.1	5.3	Arishan	2200
42	4.60	4.79	0.26	8.0	0.00590	118.1	0.267	1.47	0.49	14.1	2.02	0.193	21.9	37.5	16.6	Arishan	2250
43	4.30	7.60	0.39	8.5	0.00124	24.8	0.421	0.53	0.51	23.9	1.17	0.147	18.0	21.1	10.5	Arishan	2250
44	5.09	6.78	0.35	8.4	0.00209	41.9	0.327	5.49	0.09	16.6	1.72	0.249	22.4	19.3	11.7	Arishan	2250
45	4.55	6.82	0.33	9.0	0.00339	67.8	0.233	5.57	0.28	23.3	1.98	0.251	28.3	23.6	12.2	Arishan	2250
46	3.88	9.51	0.33	12.5	0.00457	91.3	0.304	1.95	0.58	12.1	2.86	0.355	23.6	34.5	22.4	Arishan	2200
47	4.48	5.52	0.22	10.9	0.00150	30.0	0.301	1.55	0.36	9.1	1.46	0.300	27.7	32.7	14.7	Arishan	2200
48	3.85	7.73	0.26	12.9	0.00218	43.5	0.256	2.20	0.41	11.0	1.89	0.275	26.0	32.7	14.3	Arishan	2100
49	4.30	13.50	0.53	11.1	0.00147	29.4	0.341	0.29	0.61	39.8	1.87	0.222	24.3	32.4	16.6	Arishan	2000
50	4.15	12.04	0.60	8.7	0.00152	30.4	0.291	3.75	1.36	30.1	2.97	0.300	29.5	28.6	21.9	Arishan	2000
51	4.80	9.22	0.44	9.1	0.00089	17.8	0.330	2.05	0.53	33.7	2.18	0.292	13.2	29.2	15.2	Arishan	2000
52	5.00	4.70	0.31	6.6	0.00078	15.6	0.467	1.92	1.21	23.5	1.77	0.159	27.4	30.0	17.5	Chuyunshan	900
53	4.50	10.60	0.37	12.5	0.00079	15.7	0.190	0.31	0.20	32.2	1.61	0.192	18.2	15.5	20.4	Chuyunshan	880
54	4.90	5.91	0.31	8.3	0.00120	23.9	0.294	1.44	0.60	20.3	1.63	0.125	20.2	52.5	17.3	Chuyunshan	1000

* % of oven dry weight; ** m.e. per 100 grams oven dry weight.

Key to symbols: pH=soil reaction; O.M.=organic matter; Total N=total nitrogen; C/N ratio=carbon-nitrogen ratio; Avail. P=available phosphorus; Exc. K=exchangeable potassium; Exc. Ca=exchangeable calcium; Exc. Mg=exchangeable magnesium; C.E.C.=cation exchange capacity.

Table 2

Chemical composition of the Cryptomeria nursery soils and seedling needles

Sample No.	Chemical composition of the Cryptomeria nursery soils: pH	O.M. (%)	Total N (%)	C/N ratio	Avail. P (%)	Avail. P lb./A.	Exc. K (m.e.)	Exc. Ca (m.e.)	Exc.Mg (m.e.)	C.E.C. (m.e.)	Chemical composition of the needles of Cryptomeria seedlings: N (%)	P (%)	K (m.e.)	Ca (m.e.)	Mg (m.e.)	Age of seedlings	Sampling location
55	5.00	7.48	0.33	9.9	0.00243	48.5	0.579	1.95	0.45	25.6	1.87	0.294	36.9	29.4	13.5	1-1	Pahsienshan Nursery
56	4.90	6.05	0.28	9.4	0.00033	6.4	1.031	0.89	0.36	20.8	1.94	0.450	45.1	33.5	12.6	1-0	Pahsienshan Nursery
57	4.75	13.97	0.39	15.6	0.00144	29.0	0.416	5.27	1.05	35.3	2.77	0.191	36.0	48.2	15.6	1-0	Tayenshan Nursery
58	4.52	10.57	0.51	9.0	0.00072	14.5	0.301	1.32	0.45	32.9	1.53	0.087	35.3	45.2	16.5	1-1	Tayenshan Nursery
59	4.31	6.97	0.26	11.7	0.00077	15.4	0.225	0.34	0.44	25.0	1.29	0.088	39.8	27.3	6.5	1-0	Chuyunshan Nursery
60	4.47	5.82	0.25	10.1	0.00077	15.4	0.386	0.42	0.13	21.4	2.01	0.179	41.8	35.4	12.2	1-0	Chuyunshan Nursery
61	4.43	3.02	0.14	9.4	0.00034	6.7	0.108	0.70	0.21	11.9	0.88	0.082	20.6	39.6	6.7	1-1	Chuyunshan Nursery
62	5.23	4.92	0.21	10.2	0.00110	22.0	0.267	3.68	0.62	13.2	0.94	0.345	43.1	49.5	9.5	2-0	Arishan Nursery

Table 3

Arithmetic means of the chemical composition of Cryptomeria forest and nursery soils

Factors	Means of the forest soils	Means of the nursery soils	Difference between the means of forest and nursery soils	
			Difference in means	Value of "t"
Soil reaction (pH)	5.11±0.114	4.70±0.106	0.41	1.903
Organic matter (%)	8.44±0.408	7.35±1.138	1.09	1.302
Total N (%)	0.38±0.021	0.30±0.038	0.08	1.677
Avail. P. (%)	0.0027±0.00046	0.00099±0.00023	0.00171	1.115
Exc. K (m.e.)	0.38±0.027	0.414±0.094	0.034	0.321
Exc. Ca (m.e.)	4.07±0.799	1.82±0.584	2.25	1.463
Exc. Mg (m.e.)	1.50±0.192	0.46±0.093	1.04	2.293*
C. E. C. (m.e.)	25.44±1.293	23.3±2.754	2.14	0.704

* Significant at the 5% level.

The relationships between the fertility factors in the soils were calculated. The carbon-nitrogen ratio of the organic matter in the Cryptomeria forest soils ranges from 5.6-14.3 and the mean value is 9.8. This mean value is slightly higher than that of the China fir forest soils (1).

A positive correlation (r=0.501) is found between the content of available phosphorus in the Cryptomeria forest soils and the pH values. The regession equation is $\hat{Y}=0.00211X-0.00808$. Furthermore, the result of the present study also shows that the available phosphorus level in a great number of the Cryptomeria forest soils is lower than the mean value. Such result is consistent with that of the China fir forest soils (1).

The amounts of total nitrogen and cation exchange capacity in the Cryptomeria forest soils are significantly correlated to the amount of organic matter as shown in Table 4. The coefficients are 0.900 in the case of total nitrogen and 0.705 in the case of cation exchange capacity. Their regressions are $\hat{Y}=0.057X-0.101$ for the total nitrogen, and $\hat{Y}=3.083X-0.580$ for the cation exchange capacity. However, no significant relationship is observed between these factors in the nursery soils.

Although significant linear correlations for the contents of exchangeable potassium and magnesium in the China fir forest soils to the cation exchange capacity have been observed (1), no significant correlation between these factors in the Cryptomeria forest soils in the present study is found.

Table 4

Linear correlation and regression coefficients for the fertility factors in the Cryptomeria forest and nursery soils.

Size of sample	Kinds of soil	Fertility factors tested	Linear correlation coefficient, r	Regression coefficient	
				Coefficient	Value of "t"
54	F.S.	O.M. and Total N	0.900**	0.057	14.770**
54	F.S.	O.M. and C.E.C.	0.705**	3.083	9.382**
54	F.S.	C.E.C. and Exc. K	0.072	—	—
54	F.S.	C.E.C. and Exc. Ca	0.249	—	—
54	F.S.	C.E.C. and Exc. Mg	0.167	—	—
54	F.S.	pH and Avail. P	0.501**	0.00211	4.258**
8	N.S.	O.M. and Total N	0.700	—	—
8	N.S.	O.M. and C.E.C.	0.597	—	—
8	N.S.	C.E.C. and Exc. K	0.149	—	—
8	N.S.	C.E.C. and Exc. Ca	0.685	—	—
8	N.S.	C.E.C. and Exc. Mg.	−0.052	—	—
8	N.S.	pH and Avail. P	0.479	—	—

**Significant at the 1% level.

Key to symbols: F.S.=Cryptomeria forest soils; N.S.=Cryptomeria nursery soils.

2. Foliar analysis

In attempting to evaluate the effects of various nutrients in soils, soil analysis was supplemented with analysis of the foliage. The chemical composition of the needles of Cryptomeria trees is also recorded in Table 1. The chemical composition of the needles of Cryptomeria seedlings grown in the nurseries is listed in Table 2. The arithmetic means of the chemical composition of the foliage of trees and seedlings are shown in Table 5.

The arithmetic means for the contents of potassium and calcium in the needles of seedlings are significantly higher (.05 and .01, respectively) than those of trees. On the other hand, the mean for the amount of magnesium in the needles of seedlings is smaller with statistical significance (.01) than that of trees. In fact, the level of exchangeable magnesium in the Cryptomeria forest soils averages higher than that of the nursery soils in the present study. The trees, therefore, may accumulate more magnesium in the foliage and decrease concomitantly the absorption of potassium and calcium. The differences between the means for the contents of nitrogen and phosphorus in the needles of trees and those of seedlings are not significant.

Table 5

Arithmetic means of the chemical composition of Cryptomeria tree and seedling needles

Nutrient elements	Means of the tree needles	Means of the seedling needles	Difference between the means of tree and seedling needles	
			Difference in means	Value of "t"
N (%)	1.92±0.062	1.65±0.207	0.27	1.896
P (%)	0.24±0.011	0.215±0.006	0.025	0.991
K (m.e.)	29.63±1.394	37.3±2.520	7.73	2.160*
Ca (m.e.)	28.29±1.221	38.5±2.807	10.21	3.710**
Mg (m.e.)	19.77±0.842	11.6±1.246	8.17	5.048**

* Significant at the 5% level; ** Significant at the 1% level.

The relationship between available nutrient in soils and mineral composition in tree foliage has been reported by some investigators. Chen (1) has found that the contents of nitrogen and phosphorus in the needles of China fir in Taiwan were positively significantly correlated with the concentrations of the total nitrogen and available phosphorus observed in the forest surface soils. Thomson and McComb (10) have reported that the contents of potassium and calcium in the leaves of black walnut in southeasthern Iowa were significantly correlated with the amounts of exchangeable potassium and calcium found in the surface soils. As in that area, a limiting supply of potassium and/or calcium were the most important factors associated with poor walnut growth. Tomm (9) found a positive linear correlation between nitrogen addition and needles nitrogen of Scots pine in Sweden.

In the present study, the amounts of phosphorus and magnesium in the needles of Cryptomeria trees are statistically correlated with the available phosphorus and exchangeable magnesium observed in the Cryptomeria forest surface soils (Table 6). Their regression equations are $\hat{Y}=0.219+7.79X$ for the foliage phosphorus on the available phosphorus of soils, and $\hat{Y}=15.882+2.592X$ for the foliage magnesium on the exchangeable magnesium of soils. These relationships indicate that these elements, especially exchangeable magnesium, may be limiting Cryptomeria growth on the less productive soils.

Table 6

Linear correlation and regression coefficients between the nutrients of Cryptomeria soils and foliage

Size of sample	Nutrient elements tested		Linear correlation coefficient, r	Regression coefficient	
				Coefficient	Value of "t"
	Forest soils	Tree needles			
54	Total N	N	0.056	—	—
54	Avail. P	P	0.346*	7.790	2.668*
54	EXc. K	K	0.215	—	—
54	Exc. Ca	Ca	−0.091	—	—
54	Exc. Mg	Mg	0.475**	2.592	3.886**
	Nursery soils	Seedling needles			
8	Total N	N	0.005	—	—
8	Avail. P	P	−0.022	—	—
8	Exc. K	K	0.573	—	—
8	Exc. Ca	Ca	0.702	—	—
8	Exc. Mg	Mg	0.400	—	—

* Significant at the 5% level; ** Significant at the 1% level.

3. Fertilizer tests

Table 7 presents the chemical properties of the soils used for pot cultures. Both the soils collected at Chuyunshan are Dah-an sandy clay loam (16). The contents of various factors concerned with the fertility of both Chuyunshan soils #1 and #2 are low, except the exchangeable potassium in the soil #1, as compared with the means of Cryptomeria forest soils studied. In comparison with the fertility of soil #2, soil #1 contains lesser available phosphorus and greater amount of exchangeable potassium. Therefore, seedlings grown on these two kinds of soil responded differently with fertilizer applications.

Table 7

The chemical properties of the soils used

Soil	pH	Organic matter (%)	Total N (%)	Avail. P (%)	Exc. K (m.e.)	Exc. Ca (m.e.)	Exc. Mg (m.e.)	C.E.C. (m.e.)
Soil #1	4.80	5.78	0.29	0.00068	0.731	1.27	0.39	21.3
Soil #2	4.90	5.93	0.31	0.00120	0.294	1.44	0.60	20.3

Tables 8 and 11 reveal the mean height, dry weight of shoot and roots, and chemical composition of Cryptomeria seedlings on Chuyunshan soils #1 and #2, respectively. The seedlings grown on soil #1 respond significantly with fertilizer applications (Table 9). However, no marked response for the seedlings grown on soil #2 with various treatments is observed (Table 12).

Table 8

Mean height, dry weight and chemical composition of the Cryptomeria seedlings grown on soil #1

Treatments	Mean height of shoot (cm.)	Mean dry weight of shoot (gm.)	Mean dry weight of roots (gm.)	Chemical composition of needles				
				N (%)	P (%)	K (m.e.)	Ca (m.e.)	Mg (m.e.)
Control	11.7	1.32	0.73	2.71	0.122	32.0	33.8	11.8
N_1	12.3	1.21	0.77	2.87	0.111	38.4	32.1	10.8
P_1	14.4	1.98	1.02	2.23	0.138	31.1	31.5	11.4
K_1	12.1	1.31	0.81	2.15	0.111	29.4	32.6	8.4
P_1K_1	15.2	1.73	0.78	1.91	0.147	25.3	38.3	6.7
N_1K_1	13.5	1.13	0.54	2.55	0.163	44.0	33.8	11.8
N_1P_1	17.2	1.89	0.85	2.63	0.209	32.3	33.5	18.3
$N_1P_1K_1$	15.9	1.72	0.81	2.63	0.209	43.3	33.5	9.5
$N_1P_1K_1Ca$	16.5	1.78	0.88	2.47	0.180	32.6	33.9	11.8
$N_1P_1K_1Mg$	17.7	2.11	0.87	2.23	0.188	49.7	34.2	12.6
$N_1P_1K_1CaMg$	17.4	1.93	0.91	2.39	0.163	43.6	52.2	8.8

Table 9

Analysis of variance of the mean heights of seedlings on soil #1 with various treatments

Source of variation	Degrees of freedom	Sum of squares	Mean square	Observed F value	F .05 value	F .01 value
Total	43	346.61				
Treatments	10	200.20	20.02	4.51**	2.13	2.92
Pots having same treatment	33	146.41	4.43			

** Significant at the 1% level.

On the basis of increased mean height, the seedlings on soil #1 with N_1P_1 treatment show significant response (Table 10). However, when another element (or elements) was added to N_1P_1 fertilizer as in $N_1P_1K_1$, $N_1P_1K_1Ca$, $N_1P_1K_1Mg$, and $N_1P_1K_1CaMg$ treatments, this additional nutrient gave little effect on the growth of seedlings. It is worthy of note that there is a tendency to depress the absorption of magnesium in the seedlings when either one or both potassium and calcium are added to the soils of the pot cultures.

Table 10

Differences among the mean heights of seedlings on soil #1 with various treatments

Treatments	Mean height (cm.)	Differences among the mean heights (cm.)									
$N_1P_1K_1Mg$	17.7	6.0**	5.6**	5.4**	4.2**	3.3*	2.5	1.8	1.2	0.5	0.3
$N_1P_1K_1CaMg$	17.4	5.7**	5.3**	5.1**	3.9*	3.0	2.2	1.5	0.9	0.2	
N_1P_1	17.2	5.5**	5.1**	4.9**	3.7*	2.8	2.0	1.3	0.7		
$N_1P_1K_1Ca$	16.5	4.8**	4.4**	4.2**	3.0	2.1	1.3	0.6			
$N_1P_1K_1$	15.9	4.2**	3.8*	3.6*	2.4	1.5	0.7				
P_1K_1	15.2	3.5*	3.1*	2.9	1.7	0.8					
P_1	14.4	2.7	2.3	2.1	0.9						
N_1K_1	13.5	1.8	1.4	1.2							
N_1	12.3	0.6	0.2								
K_1	12.1	0.4									
Control	11.7										

*Significant at the 5% level; ** significant at the 1% level.

$\bar{D}_{.05}=2.035\times\sqrt{4.43\times2/4}=3.03$; $\bar{D}_{.01}=2.734\times\sqrt{4.43\times2/4}=4.07$

Table 11

Mean height, dry weight and chemical composition of the Cryptomeria seedlings grown on soil #2

Treatments	Mean height of shoot (cm.)	Mean dry weight of shoot (gm.)	Mean dry weight of roots (gm.)	Chemical composition of needles				
				N (%)	P (%)	K (m.e.)	Ca (m.e.)	Mg (m.e.)
Control	16.7	1.73	0.85	2.07	0.101	25.9	35.5	11.8
N_1	15.8	1.43	0.70	2.55	0.111	36.3	32.1	16.4
P_1	16.2	1.74	0.78	1.99	0.150	17.0	35.0	6.3
K_1	15.4	1.63	0.81	2.39	0.104	39.6	34.2	13.5
P_1K_1	18.4	2.36	0.98	1.74	0.101	32.6	29.8	11.8
N_1K_1	15.0	1.54	0.66	2.23	0.108	21.3	31.7	6.3
N_1P_1	16.2	1.68	0.70	2.55	0.138	35.1	29.4	14.7
$N_1P_1K_1$	16.6	1.96	0.91	2.47	0.134	35.7	30.1	13.5
$N_1P_1K_1Ca$	17.4	2.34	0.84	1.74	0.101	42.9	45.8	12.9
$N_1P_1K_1Mg$	17.7	2.18	0.93	1.91	0.127	36.9	32.8	14.7
$N_1P_1K_1CaMg$	17.7	2.05	1.08	1.91	0.111	26.5	52.0	11.8

Table 12

Analysis of variance of the mean heights of seedlings on soil #2 with various treatments

Source of variation	Degrees of freedom	Sum of squares	Mean square	Observed F value	$F_{.05}$ value
Total	43	194.43			
Treatments	10	44.51	4.45	0.98	2.69
Pots having same treatment	33	149.92	4.54		

4. Fertility standards for growth of Cryptomeria seedlings.

After making a comparative and detailed study on the fertility of Cryptomeria forest and nursery soils, the fertility standards for growing this species in nurseries may be made as shown in Table 13. With slight modifications, the mean values for various factors concerned with the fertility of Cryptomeria forest soils may be adapted as standards for the maintenance of fertility of nursery soils. These standards, except having higher levels of total nitrogen and available phosphorus, are similar to those for growing China fir seedlings (1).

Table 13

Fertility standards for growing Cryptomeria seedlings in nurseries

Soil reaction (pH)	Total N (%)	Available P (%)	Available P lb./A.	Exchangeable K (m.e.)	Exchangeable Ca (m.e.)	Exchangeable Mg (m.e.)	Cation exchange capacity (m.e.)
5.2	0.38	0.0027	54	0.40	4.5	1.5	25

In comparison with the standards, the contents of total nitrogen and exchangeable potassium in some nursery soils studied are in the neighborhood of the standards. However, the levels of available phosphorus, and exchangeable calcium and magnesium in all the nursery soils studied are far below the standards. Therefore, it is reasonable to believe that the fertility standards will meet the requirements of Cryptomeria seedlings in nurseries.

A desirable reaction range of nursery soils between pH 5 and 5.5 has been suggested for most coniferous species (13). The reaction of the nursery soils studied are mostly less than pH 5, even some of them below pH 4.5. At a high degree of acidity, below pH 4.7, seedlings may suffer from the low availability of nitrogen, phosphorus, potassium, and other bases. It is suggested to keep the soil reaction at pH 5.2 for growing Cryptomeria seedlings in nurseries.

All the nursery soils studied are low in exchangeable magnesium. The seedlings, therefore, accumulate less magnesium in the needles. A critical deficiency of magnesium is encountered frequently in acid-treated soils of forest nurseries and in soils depleted by cultivation (13). Furthermore, magnesium deficiency symptoms in 1-0 and 1-1 Cryptomeria seedlings in the nurseries have been observed at sampling time by the author. Magnesium amounts found in the needles showing deficiency symptoms are 6.5 m.e. for 1-0 seedlings, 6.7 m.e. for 1-1 seedlings (Table 2), and 10.3 m.e.* for 1-1 seedlings collected from Tayenshan Nursery. Magnesium nutrient for Cryptomeria seedlings in nurseries in Taiwan should not be neglected.

Though the content of organic matter in the nursery soils studied is mostly in the neighborhood of the mean for the factor in Cryptomeria forest soils, it should be mentioned that one of the important keys to the nursery soil fertility problem is the maintenance of an adequate supply of organic matter. This is particularly significant with regard to the nitrogen economy in the soil. Furthermore, the pine seedlings grown on the soil treated with chemical fertilizers plus peat show higher survival percentage after planting in the field than the seedlings on the soil treated with chemical fertilizers alone (13). It is suggested to use humus or green manure and stable manure along with chemical fertilizer for the maintenance of fertility of nursery soil.

SUMMARY

Soil and foliar analyses as well as fertilizer tests were used for the study of the fertility of Cryptomeria forest and nursery soils. Fifty four samples each of soil and of Cryptomeria tree foliage were collected from the Cryptomeria forest lands; eight samples each of soil and of the needles of Cryptomeria seedlings were collected from the nurseries. Soil was analysed for soil reaction, organic matter, total nitrogen, available phosphorus, exchangeable potassium, calcium and magnesium, and cation exchange capacity; foliage was analysed for nitrogen, phosphorus, potassium, calcium and magnesium elements.

The arithmetic mean for the content of exchangeable magnesium in the Cryptomeria forest soils is significantly greater than that of the nursery soils. The carbon-nitrogen ratio of the organic matter in the forest soils ranges from 5.6-14.3, and the mean is 9.8. A linear correlation is found between the level of available phosphorus in the forest soils and the pH values. Total nitrogen and cation exchange capacity in the forest soils are significantly correlated with the organic matter. These relationships are not found in the nursery soils.

The means for the concentrations of potassium and calcium in the needles of seedlings are significantly greater than those of trees. On the contrary, the mean for the magnesium in the tree foliage is greater with statistical significance than that of seedlings.

*Unpublished data

The concentrations of phosphorus and magnesium in the tree foliage show significant positive correlation with the contents of available phosphorus and exchangeable magnesium found in the Cryptomeria forest surface soils. These relationships indicate that these elements, especially exchangeable magnesium, may be limiting Cryptomeria growth on poor soils.

The seedlings grown on Chuyunshan soil #1 responded significantly with the fertilizer applications. However, no significant response for the seedlings grown on Chuyunshan soil #2 with fertilizers has been observed.

Fertility standards for maintenance of the fertility of nursery soils for growing Cryptomeria seedlings are suggested.

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培育柳杉幼苗的肥力標準之研究

陳賢芳

本研究係以土壤分析，針葉分析，及肥料試驗等三種方法，探討柳杉林土壤及苗圃土壤之肥力，進而擬定土壤肥力標準，以供苗圃培育柳杉苗之依據。適度土壤肥力培育之幼苗，不獨生長迅速，發育健壯，且有較高之成活潛力。

柳杉林地土壤及林木針葉各五十四個樣本，苗圃土壤及柳杉苗針葉各八個樣本，及肥料試驗培育之幼苗針葉，均作化學之分析，以觀察土壤肥力變化，及針葉養分差異情形。土壤分析之項目有：土壤反應、有機物、全氮量、有效性磷、交換性鉀、交換性鈣、交換性鎂、及陽離子交換量。針葉分析項目有：氮、磷、鉀、鈣、及鎂等養分元素。

柳杉林土壤各肥力因子之平均值大部份比較苗圃者高，其中以交換性鎂爲顯著。至於柳杉林土壤各肥力因子間之關係有：土壤與有機物之碳氮比幅度爲 5.6～14.3，平均值爲 9.8。有效性磷與土壤反應成一極顯著之正相關，即土壤 pH 值升高時，有效性磷量隨之增加。此外，全氮量及陽離子交換量分別與土壤有機物成極顯著之正相關。

苗圃培育之柳杉苗，其針葉所含之鉀鈣兩元素之平均值均顯著的比林木者高。至於氮磷鎂三元素之平均值則比林木者爲低，其中以鎂之相差至爲顯著。

針葉養分量與土壤養分量間之關係，經發現者有磷鎂兩元素分別與柳杉林地表土之有效性磷及交換性鎂成顯著性之正相關。此類相關顯示在肥力較低之柳杉林地，此兩元素可能限制柳杉之生長，其中以交換性鎂之影響較大。

生長於出雲山一號土壤之盆栽柳杉苗，對施用之肥料有極顯著之反應；生長於出雲山二號土壤之幼苗對所施肥料之反應則不顯著。盆栽幼苗針葉分析結果顯示一種趨勢，即盆栽土壤如加入鉀鈣肥料，或兩者中之任一種，幼苗吸收鎂素份量隨而減少。

柳杉林土壤各肥力因子之平均值經稍予修改後採用爲肥力標準，可用以培育柳杉苗。各值分列於下：

土壤反應	全氮量	有效性磷		交換性鉀	交換性鈣	交換性鎂	陽離子交換量
(pH)	(%)	(%)	lb./A.	(m.e.)	(m.e.)	(m.e.)	(m.e.)
5.2	0.38	0.0027	54	0.40	4.5	1.5	25

本研究所用之苗圃土壤其反應大部份低於 pH 5，其中亦有低於 pH 4.5。土壤酸度過高，容易降低養分之有效性。因之苗圃土壤之 pH 值宜予提高，以保持在 pH 5.2 爲佳。又前述苗圃土壤所含之交換性鎂亦低，一年生及二年生柳杉苗顯示缺鎂病徵頗爲普遍，宜從提高土壤之 pH 值及施用含鎂肥料予以補救。柳杉苗圃土壤有機物之平均值雖與柳杉林土壤有機物平均值相接近，但苗圃土壤有機物如能保持適當份量，不獨土壤氮素可經濟利用，且可提高幼苗之成活潛力。因此，宜併施有機及化學肥料以保持土壤肥力。