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

CHEN HSIEN-FANG

INTRODUCTION

China fir (*Cunninghamia lanceolata* (Lamb.) Hook.) is an economically important coniferous species in Taiwan. It grows fast and is distributed at low elevation; therefore, in recent years this species is often planted on reforested lands or to replace hardwood forests. The need for seedlings raised in nurseries for planting is increasing annually. An important problem is also presented, that is how to improve the seedlings quality and to minimize the mortality after transplanting in the field. Establishment of fertility standards for growing this species in the nursery is one of the ways to improve the nursery stock quality and it will then increase seedlings growth and survival potential.

The application of fertilizers to the nursery soils may give seedlings good growth. However, many evidences show that seedlings of maximum weight produced by heavy application of fertilizers usually have succulent tissues, and other unsatisfactory properties which lower their ability to survive on cut-over lands.

Wilde (13), Wilde and Patzer (16), and Youngberg and Austin (17) have pointed out the nursery stock may possess a high survival potential when they grow with adequate fertility in nursery soil. They set up fertility standards for forest species by analysed numerous soils supporting natural reproduction of the species during the past years. The mean values of these determinations, representing the average condition of natural seedbeds, were adapted as standards for the maintenance of fertility in nursery soils. As many years' experience has shown, these standards facilitate the production of normally developed nursery stock possessing a high survival potential.

Furthermore, foliar analysis has been widely employed as a measure of the availability of nutrients in the soil (2, 6, 10), as the concentrations of nutrients present in the foliage provide a consistent guide to the adequacy, or otherwise, of the nutrients supply to the plants.

The author is grateful to the Joint Commission on Rural Reconstruction for the financial support which enabled him to make this study possible. The supplying of nursery soils and China fir seedlings used in this study by Puli Nursery, Yuchih Nursery, Shihtowi Nursery and Chuyunshan Nursery, and the fine technical assistance of Mr. Sun Ch'i, Mr. Liu Kuo-chun, Miss Kuo Ching-chih and Miss Lin Fu-mei are very much appreciated.

For the purpose of establishing fertility standards for growing China fir seedlings in nurseries, numerous China fir forest and nursery soils as well as needles were chemically analysed for various factors concerned with the fertility of the soils. Two kinds of forest soil were used for fertilizer tests. The results are presented in this paper.

METHODS

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

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

Soils for fertilizer tests were separately collected from the China fir forests at Chungkeng and Chuyunshan. Pot cultures with China fir seedlings were made out of doors at Tatushan. Six-inch pots were used, with three seedlings per pot in quadruplicate. In these tests 2200 grams of soil were weighed into a pot and then fertilized with various treatments as shown in Tables 8 and 10. The designations 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 1000 pounds $CaCO_3$ per acre and the magnesium, at the rate of 20 pounds Mg per acre. The China fir seedlings at about 3 cm. height were transplanted in the pots on June 27, 1959, and they were harvested on December 5, 1959. 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 quadruplicate 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(9); 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 (7). 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 (9). Organic matter of the soil was determined by the potassium dichromate method (9). Total nitrogen was determined as described above for plant tissue. Available phosphorus was extracted with dilute sulfuric acid (12) and then estimated by comparing with phosphorus standards on a colorimeter. Cation exchange capacity was determined by a method modified from Peech et al. (8). 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 methods used in analysis of the plant tissue for potassium, calcium and magnesium elements.

RESULTS AND DISCUSSION

1. Soil fertility.

Tables 1 and 2 reveal the chemical composition of China fir forest soils and of nursery soils, respectively. Soil fertility varies greatly with different kinds of soil. Table 3 presents the arithmetic means of the chemical composition of China fir forest and nursery soils. Considerable differences between the arithmetic means for the various factors concerned with the fertility of forest soils and nursery soils were calculated. The means for the contents of organic matter, total nitrogen, exchangeable potassium and cation exchange capacity of the forest soils are greater with statistical significance than those of the nursery soils (Table 3). Although the nursery soils studied have been fertilized with compost and/or chemical fertilizers for the growing seedlings in the year of soil sampling, it is worthy of note that the amounts of various nutrients in most of the nursery soils are far below the levels of means for the contents of these factors in the forest soils.

Table 1

Chemical composition of the China fir forest soils and tree needles

Sample No	Chemical composition of the China fir forest soils										Chemical composition of the needles of China fir trees					Sampling location	
	pH	O.M. (%)*	C/N ratio	Total N (%)	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	6.65	1.72	6.2	0.12	0.00959	192	0.20	3.51	1.05	6.80	1.63	0.251	37.7	48.2	20.0	Kulu, Rotung	—
2	5.30	5.07	11.6	0.19	0.00186	37	0.25	4.73	1.29	18.56	1.54	0.334	64.5	22.5	19.4	Ayu, Wenshan	350
3	4.90	6.26	10.5	0.26	0.00214	43	0.35	2.17	1.05	23.03	1.81	0.294	47.5	39.1	17.7	Ayu, Wenshan	340
4	4.70	7.29	10.2	0.31	0.00052	10	0.19	0.20	0.52	22.07	2.10	0.226	58.2	17.1	24.0	Ayu, Wenshan	330
5	5.85	5.24	6.9	0.33	0.00256	51	0.61	6.28	1.59	22.25	2.44	0.277	47.9	34.8	20.2	Ayutunghouhsi, Wenshan	240
6	5.95	5.52	5.9	0.41	0.01057	271	0.94	15.23	6.23	39.06	1.85	0.282	53.7	9.6	10.7	Huayuan, Chutung	800
7	4.30	14.00	10.5	0.58	0.00176	35	0.36	7.07	1.62	41.84	1.64	0.078	27.3	12.3	7.8	Huayuan, Chutung	930
8	4.40	6.89	7.5	0.40	0.00201	40	0.36	0.94	0.62	28.90	2.05	0.188	53.7	28.6	14.3	Huayuan, Chutung	985
9	4.55	8.23	7.0	0.51	0.00959	192	0.75	8.39	0.96	26.46	1.93	0.318	40.9	18.7	13.5	Huayuan, Chutung	870
10	6.10	5.08	7.9	0.28	0.00159	32	0.75	9.18	2.37	21.03	1.72	0.226	34.5	42.8	16.4	Huayuan, Chutung	630
11	5.62	3.88	6.2	0.27	0.00034	7	0.51	6.75	2.45	21.61	1.42	0.235	35.6	26.2	13.2	Huayuan, Chutung	440
12	6.70	6.18	7.1	0.38	0.00943	189	1.12	14.39	4.29	24.46	1.89	0.345	46.2	20.3	15.6	Chingchuan, Chutung	800
13	6.65	3.58	6.5	0.24	0.00450	90	0.44	10.19	2.45	11.62	1.86	0.326	46.1	18.3	22.8	Chingchuan, Chutung	750
14	7.20	10.73	8.5	0.55	0.00910	182	0.42	19.64	6.47	30.64	2.15	0.404	54.1	16.3	18.5	Chingchuan, Chutung	760
15	6.55	7.62	7.5	0.44	0.00594	119	0.46	13.51	5.72	25.77	1.59	0.361	43.8	17.3	20.2	Chingchuan, Chutung	630
16	5.70	4.01	7.9	0.22	0.00148	30	0.81	6.26	1.53	21.08	1.43	0.208	40.3	25.4	22.7	Chingchuan, Chutung	580
17	6.80	4.22	7.6	0.24	0.00832	166	1.37	12.49	4.47	21.18	1.39	0.343	49.7	23.4	19.2	Chingchuan, Chutung	570
18	5.75	3.45	6.5	0.23	0.00085	17	0.75	10.56	2.47	26.12	1.51	0.157	32.8	26.4	21.5	Taqshan, Chutung	540
19	4.80	2.73	6.2	0.19	0.00345	69	0.56	1.34	0.93	33.31	1.65	0.163	30.0	26.4	25.1	Taai, Chutung	450
20	5.20	3.19	7.3	0.19	0.00136	27	0.91	3.21	2.77	17.37	1.63	0.208	38.4	24.9	13.9	Taai, Chutung	450
21	5.35	4.36	8.6	0.22	0.00102	20	0.35	2.49	1.61	21.23	1.53	0.171	29.2	11.2	8.8	Taai, Chutung	400
22	6.10	6.86	8.5	0.35	0.00149	30	0.99	10.62	2.37	22.74	1.55	0.208	40.0	48.8	22.7	Wufeng, Chutung	330
23	4.97	1.63	5.9	0.12	0.00034	7	0.22	0.82	0.64	11.03	1.95	0.118	22.4	28.4	16.4	Shihshan, Nanchuang	220
24	4.95	3.43	7.5	0.20	0.00110	22	0.48	5.08	1.90	14.27	1.75	0.192	37.3	27.9	25.3	Tienmei, Nanchuang	230
25	5.32	3.57	7.8	0.20	0.00157	31	0.46	3.44	2.05	14.11	1.81	0.302	37.5	31.7	15.6	Nanchiang, Nanchuang	250
26	5.30	3.79	7.8	0.21	0.00085	17	0.42	3.15	1.44	18.41	1.68	0.108	36.9	30.5	25.9	Nanchiang, Nanchuang	270
27	5.80	2.73	7.4	0.16	0.00100	20	0.35	6.95	1.43	16.48	1.56	0.141	28.1	17.3	16.0	Nanchiang, Nanchuang	250
28	5.10	2.99	9.3	0.14	0.00100	20	0.35	2.11	1.01	13.63	1.78	0.118	36.6	29.0	19.4	Nanchiang, Nanchuang	220
29	5.60	3.53	7.0	0.22	0.00055	11	0.41	2.82	1.59	15.92	1.84	0.139	31.2	12.2	14.7	Tingkeng, Shuili	420
30	4.90	2.63	7.6	0.15	0.00034	7	0.17	1.16	0.62	10.54	1.07	0.131	21.6	15.2	13.3	Chungkuei, Shuili	610
31	4.41	6.08	9.8	0.27	0.00040	8	0.21	0.27	0.21	25.11	1.42	0.159	29.2	12.2	19.4	Toushe, Yuchih	670
32	4.50	4.56	7.9	0.25	0.00034	7	0.24	0.37	0.25	23.25	1.43	0.118	31.6	9.1	11.8	Toushe, Yuchih	740
33	4.55	4.82	12.3	0.17	0.00042	9	0.40	0.13	0.07	13.26	1.46	0.151	28.4	11.2	16.3	Sunmoonlake	760
34	4.65	4.86	7.5	0.28	0.00075	15	0.22	0.70	0.31	10.84	1.85	0.198	32.2	17.8	13.3	Sunmoonlake	710
35	4.45	5.05	9.5	0.23	0.00059	12	0.17	0.16	0.15	16.38	1.59	0.171	41.2	17.8	24.2	Chungming	680
36	4.80	3.80	9.2	0.18	0.00039	8	0.15	0.16	0.07	13.83	1.68	0.143	19.9	8.4	8.6	Chungming	670
37	4.80	4.94	10.2	0.21	0.00025	5	0.29	0.86	0.17	18.30	1.76	0.196	48.8	21.3	19.8	Yuchih Nursery	650
38	4.30	5.46	10.3	0.23	0.00118	24	0.31	0.76	0.31	16.46	1.60	0.016	28.6	17.3	14.1	Chuitzuliao, Yuchih	660
39	5.40	4.89	9.2	0.23	0.00084	17	0.26	2.99	0.95	12.97	1.76	0.108	41.8	19.3	11.8	Chuitzuliao, Yuchih	640
40	4.90	3.97	6.4	0.27	0.00085	17	0.31	0.53	0.31	29.05	1.46	0.024	31.6	22.3	8.8	Kanhsi, Yuchih	620

Table 1 (cont.)

Chemical composition of the China fir forest soils and tree needles

Sample No.	Chemical composition of the China fir forest soils										Chemical composition of the needles of China fir trees					Sampling location	
	pH	O.M. (%)	C/N ratio	Total N (%)	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.)
41	5.91	3.55	6.7	0.23	0.00084	17	0.54	2.98	1.17	14.08	1.79	0.056	44.0	18.3	14.7	Kanhsi, Yuchih	630
42	6.00	3.81	7.7	0.22	0.00076	15	0.31	4.40	1.00	14.53	1.72	0.037	28.0	14.2	12.9	Kanhsi, Yuchih	630
43	4.80	6.06	8.5	0.31	0.00126	25	0.25	0.39	0.28	17.24	2.03	0.157	40.3	12.2	19.4	Chuitzuliao, Yuchih	660
44	4.55	3.79	9.2	0.18	0.00055	11	0.12	0.05	0.17	15.90	1.48	0.196	17.4	6.6	13.5	Touku, Yuchih	660
45	4.70	2.95	8.6	0.15	0.00025	5	0.12	0.11	0.13	19.78	1.79	0.100	12.7	19.3	8.0	Tayen, Yuchih	640
46	4.45	6.38	9.6	0.29	0.00086	17	0.17	0.19	0.15	27.23	1.82	0.251	26.5	11.2	17.3	Liyuchueh, Puli	560
47	4.97	4.45	8.4	0.23	0.00075	15	0.12	0.11	0.15	23.82	2.24	0.306	25.7	7.1	9.5	Liyuchueh, Puli	580
48	6.20	4.25	6.6	0.28	0.00184	37	0.14	3.10	0.14	12.65	2.11	0.205	12.3	38.6	30.5	Chiukunglin, Puli	540
49	4.80	5.11	7.2	0.31	0.00293	59	0.16	1.29	0.57	14.28	1.97	0.245	38.3	17.3	15.6	Chiukunglin, Puli	530
50	4.50	11.35	10.3	0.48	0.00222	44	0.30	0.45	0.33	28.07	1.88	0.167	14.6	13.2	19.4	Tungpu, Puli	605
51	5.60	4.35	6.3	0.30	0.00100	20	0.31	10.86	0.91	13.45	1.63	0.375	29.4	11.7	20.9	Tungpu, Puli	590
52	4.45	4.13	7.8	0.23	0.00092	19	0.09	0.19	0.12	13.97	1.34	0.188	9.1	13.7	21.5	Neitilin, Puli	530
53	4.50	3.48	8.0	0.19	0.00084	17	0.12	0.28	0.10	20.33	1.58	0.171	28.9	16.3	13.3	Tingshe, Shuili	680
54	4.40	11.70	13.7	0.37	0.00113	23	0.25	0.40	0.45	32.97	1.58	0.226	26.5	22.9	18.5	Chiapaotai, Pahsienshan	960
55	5.10	5.47	8.2	0.29	0.00236	47	0.16	1.86	0.73	17.36	1.58	0.318	44.0	9.1	16.8	Chiapaotai, Pahsienshan	950
56	5.05	6.70	12.7	0.23	0.00083	17	0.22	1.17	0.48	12.70	1.74	0.159	28.1	23.4	17.7	Chiapaotai, Pahsienshan	880
57	4.45	3.65	6.6	0.24	0.00083	17	0.20	1.40	0.50	12.88	2.63	0.282	41.8	31.5	18.5	Chiapaotai, Pahsienshan	1000

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

Key to symbols: O.M.=organic matter; Avail. P=available phosphorus; Exc. K=exchangeable potassium; Exc. Ca=exchangeable calcium; Exc. Mg=exchangeable magnesium; C.E.C.=cation exchange capacity; pH=soil reaction.

Table 2

Chemical Composition of the China fir nursery soils and seedling needles

Sample No.	Chemical composition of the China fir nursery soils										Chemical composition of the needles of China fir seedlings					Sampling location	Age of seedlings
	pH	O.M. (%)	C/N ratio	Total N (%)	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.)		
58	5.50	2.45	0.20	5.7	0.00156	31.2	0.18	1.62	0.41	8.19	2.31	0.171	16.4	11.7	7.4	Puli Nursery	1-0
59	6.10	3.27	0.22	6.5	0.00189	37.8	0.28	4.76	0.87	10.39	1.42	0.162	26.5	29.4	11.0	Puli Nursery	1-0
60	4.80	3.51	0.21	7.3	0.00157	31.4	0.10	0.86	0.38	8.41	1.02	0.134	13.5	24.7	14.1	Puli Nursery	1-0
61	5.15	3.39	0.14	10.5	0.00067	13.4	0.26	2.35	1.64	11.13	1.91	0.201	43.2	28.2	11.8	Yuchih Nursery	1-0
62	5.20	2.68	0.12	9.7	0.00083	16.6	0.12	1.04	0.12	8.19	1.26	0.126	31.7	54.4	17.3	Yuchih Nursery	1-1
63	4.90	1.57	0.08	8.5	0.00155	31.0	0.15	1.31	0.26	6.96	2.07	0.273	41.3	26.6	15.0	Shihtowi Nursery	1-0
64	5.35	1.40	0.06	10.2	0.00124	24.8	0.09	0.99	0.17	5.92	0.86	0.259	24.7	45.0	14.3	Shihtowi Nursery	1-1
65	4.50	7.23	0.26	12.1	0.00085	16.8	0.14	0.43	0.07	18.37	1.42	0.086	33.4	32.3	11.4	Chuyunshan Nursery	1-0
66	4.90	2.31	0.12	8.4	0.00025	5.0	0.30	1.67	0.91	11.34	2.23	0.171	27.1	31.1	11.5	Chuyunshan Nursery	1-0

Table 3

Arithmetic means of the chemical composition of

China fir 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)	5.23±0.103	5.16±0.146	0.07	0.26
O.M. (%)	5.12±0.312	3.33±0.546	1.79	2.16*
Total N (%)	0.268±0.013	0.16±0.022	0.108	3.08**
Avail. P (%)	0.0021±0.00036	0.00116±0.00017	0.00094	1.02
Exc. K (m.e.)	0.409±0.038	0.18±0.025	0.229	2.34*
Exc. Ca (m.e.)	4.33±0.600	1.69±0.586	2.64	1.71
Exc. Mg (m.e.)	1.36±0.192	0.54±0.161	0.82	1.65
C.E.C. (m.e.)	19.86±0.952	9.88±1.153	9.98	4.03**

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

The relationships between the fertility factors of soils studied were calculated. The carbon-nitrogen ratio of the organic matter in the China fir forest soils ranges from 5.9-13.7, and the mean value is 8.3. This result is consistent with the carbon-nitrogen ratio of the organic matter in Taiwan agricultural soils (20), ranging from 6 to 12 but mostly between 8 to 10. The available phosphorus content of the arable lands in Taiwan varies with pH values of the soil (20). On acid soils, the available amount of phosphorus is very low, and it increases continuously with rising the pH values. This is also true of the relationship of these factors in the China fir forest soils. A positive linear correlation ($r=0.401$) is found between the content of available phosphorus in the forest soils and the pH values. The significant effect of available phosphorus on pH values is expressed by the regression $\hat{Y}=0.00161X-0.00632$. The results of the present study also show that the available phosphorus level in a great number of the China fir forest soils is lower than the mean value.

Table 4

Linear correlation and regression coefficients for the fertility factors in the China fir forest and nursery soils

Smple size	Kinds of soil	Factors tested		Linear correlation coefficient, r	Regression coefficient	
		X	Y		Coefficient	Value of "t"
57	F.S.	O.M.	Total N	0.860**	0.0371	13.67**
57	F.S.	O.M.	C.E.C.	0.552**	1.686	4.91**
57	F.S.	C.E.C.	Exc. K	0.308*	0.0117	2.40*
57	F.S.	C.E.C.	Exc. Ca	0.250	—	—
57	F.S.	C.E.C.	Exc. Mg	0.365**	0.0757	2.90**
57	F.S.	pH	Avail. P	0.401**	0.00161	3.37**
9	N.S.	O.M.	Total N	0.785*	0.0308	3.36*
9	N.S.	O.M.	C.E.C.	0.823**	1.80	9.47**
9	N.S.	C.E.C.	Exc. K	0.276	—	—
9	N.S.	C.E.C.	Exc. Ca	-0.053	—	—
9	N.S.	C.E.C.	Exc. Mg	0.108	—	—
9	N.S.	pH	Avail. P	0.506	—	—

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

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

The contents of total nitrogen and cation exchange capacity in the China fir forest and nursery soils are significantly correlated with the amount of organic matter as shown in Table 4. For the forest soils, the linear correlation coefficients are 0.860 in the case of total nitrogen and 0.552 in the case of cation exchange capacity; their regressions are $\hat{Y}=0.078+0.0371X$ for the total nitrogen, and $\hat{Y}=11.23+1.686X$ for the cation exchange capacity. For the nursery soils, the correletion coefficients and regression equations are 0.785 and $\hat{Y}=0.0574+0.0308X$ for the amount of total nitrogen and 0.823 as well as $\hat{Y}=3.885+1.80X$ for the cation exchange capacity compared with the content of organic matter.

The amount of available potassium in some nursery soils shows a positive correletion to the cation exchange cepacity (15). In the present study, no statistical significance has been observed for the relationship of the contents of exchangeable potassium, calcium and magnesium in the China fir nursery soils to the cation exchange capacity. However, significant linear correlations are for the concentration of exchangeable potassium in the forest soils to the cation exchange capacity ($r=0.308$), and for the exchangeable magnesium as well ($r=0.365$). The regression equations are $\hat{Y}=0.177+0.0117X$ for the exchangeable potassium on the cation exchange capacity, and $\hat{Y}=0.0757X-0.143$ for the exchangeable magnesium.

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 China fir trees is also shown in Table 1. The chemical composition of the needles of China fir seedlings on the nursery soils is listed in Table 2. Table 5 presents the arithmetic means of the chemical composition of China fir tree and seedling needles. The arithmetic mean for the content of calcium is significantly higher in the needles of seedlings on the nursery soils, while that for the level of magnesium is greater in the foliage of trees. No significant difference between the means for the amounts of nitrogen, phosphorus and potassium in the needles of the trees and those of the seedlings is observed.

Table 5

Arithmetic means of the chemical composition of China fir 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	(%)	1.74±0.038	1.61±0.171	0.13	1.10
P	(%)	0.20±0.012	0.176±0.019	0.024	0.73
K	(m.e.)	35.16±1.572	28.60±3.155	6.54	1.55
Ca	(m.e.)	21.02±1.285	31.5±3.851	10.48	2.88**
Mg	(m.e.)	16.89±0.663	12.6±0.898	4.29	2.48*

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

The relationship between nutrient supply and mineral composition in mature foliage has been observed by investigators (6,10). When only one nutrient is limiting growth, the response in the concentration of that nutrient in the leaves to increasing supplies, generally follows a curve of diminishing returns, reaching a maximum at levels of supply beyond those optimal for growth. In the suboptimal range of nutrient supply, concentrations rising linearly throughout the range of supply have been observed.

Thomson and McComb (11) have found that the amounts of potassium and calcium in the leaves of black walnut in southeastern Iowa were significantly correlated with the level 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. Chen (1) also reported that the contents of magnesium and phosphorus in the needles of Cryptomeria in Taiwan were positively significantly correlated with the concentrations of the exchangeable magnesium and available phosphorus observed in the surface soils.

Table 6

Linear correlation and regression coefficients between the nutrients of soils and of China fir foliage

Sample size	Nutrient elements tested		Linear correlation coefficient r	Regression coefficient	
				Coefficient	Value of "t"
	Forest soils	Tree foliage			
57	Total N	N	0.289*	0.782	2.14*
57	Avail. P	P	0.649**	19.911	6.17**
57	Exc. K	K	0.099	—	—
57	Exc. Ca	Ca	0.152	—	—
57	Exc. Mg	Mg	0.027	—	—
	Nursery soils	Seedling foliage			
9	Total N	N	−0.036	—	—
9	Avail. P	P	−0.074	—	—
9	Exc. K	K	0.245	—	—
9	Exc. Ca	Ca	−0.200	—	—
9	Exc. Mg	Mg	−0.358	—	—

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

In the present study the contents of nitrogen and phosphorus in the needles of China fir trees were significantly correlated with the levels of total nitrogen and available phosphorus found in the forest surface soils (Table 6). The regression for the nitrogen of tree foliage on total nitrogen of the soils is $\hat{Y}=1.53+0.782X$. The significant effect of the amount of phosphorus in the tree foliage on available phosphorus in the surface soils is expressed by the regression $\hat{Y}=19.911X-0.0218$. The positive and remarkable linear correlation coefficients of total nitrogen and available phosphorus in the China fir forest surface soils with foliage nitrogen and phosphorus ($r=0.289$ and 0.649) indicate that these elements may be limiting China fir growth on poorer soils. Of these factors, phosphorus was the most important factor limiting the China fir growth on the soils studied.

3. Fertilizer tests

Table 7 reveals the chemical properties of the soils used for pot cultures. The soils collected at Chungkeng and Chuyunshan are Dah-an sandy clay loam (19). The concentrations of various factors concerned with the fertility of Chungkeng soil were low as compared with the means for the factors in the China fir forest soils. With higher levels of total nitrogen and exchangeable potassium Chuyunshan soil was more productive than Chungkeng soil. Seedlings grown on these two kinds of soil, therefore, responded differently with fertilizer applications.

Table 7

Chemical properties of the soils used for pot cultures

Soil	pH	Organic matter (%)	Total N (%)	Avail. P.		Exc. K	Exc. Ca	Exc. Mg	C.E.C.
				(%)	lb./A.	(m.e.)	(m.e.)	(m.e.)	(m.e.)
Chungkeng	5.40	2.82	0.13	0.00092	18.3	0.255	1.67	0.81	12.25
Chuyunshan	4.88	6.83	0.36	0.00087	17.4	0.733	1.96	1.15	22.80

Tables 8 and 10 present the mean height, dry weight and chemical composition of China fir seedlings on Chungkeng soil and on Chuyunshan soil, respectively, On the basis of increased mean height, the seedlings on Chungkeng soil with various fertilizer treaments are mostly taller than the control plants, but the increases are not statistically significant. On the other hand, the seedlings on Chuyunshan soil responded very significantly with all the fertilizers except $N_1P_1K_1Ca$ treatment as compared with the control plants (Tables 11 and 12). The seedlings with P_1K_1 treatment yielded the greatest height increase. However, when another element (or elements) was added to P_1K_1 fertilizer as in $N_1P_1K_1$, $N_1P_1K_1Ca$, and $N_1P_1K_1CaMg$ treatments, the growth of seedlings was depressed.

Table 8

Mean height, dry weight and chemical composition of the China fir seedlings grown on Chungkeng soil

Treatments	Mean height of shoot (cm.)	Mean dry weight of shoot (gm.)	Chemical composition of needles				
			N (%)	P (%)	K (m.e.)	Ca (m.e.)	Mg (m.e.)
Control	7.4	0.37	1.27	0.105	28.5	25.0	22.5
P_1K_1	8.1	0.44	1.41	0.291	47.5	27.6	16.2
N_1K_1	7.1	0.37	1.36	0.139	41.0	40.2	16.8
N_1P_1	7.5	0.40	1.34	0.260	39.6	32.2	19.7
$N_1P_1K_1$	8.4	0.42	1.47	0.306	42.5	32.7	21.1
$N_1P_1K_1Ca$	9.8	0.53	1.23	0.338	29.2	48.1	11.2
$N_1P_1K_1CaMg$	8.0	0.53	1.71	0.285	28.6	58.6	25.3

Table 9

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

Source of variation	Degrees of freedom	Sum of squares	Mean square	Observed F value	$F_{.05}$ value	$F_{.01}$ value
Total	27	49.66				
Treatments	6	18.99	3.17	2.17	2.57	3.81
Pots having same treatment	21	30.67	1.46			

Table 10

Mean height, dry weight and chemical composition of the China fir seedlings grown on Chuyunshan soil

Treatments	Mean height of shoot (cm.)	Mean dry weight of shoot (gm.)	Chemical composition of needles				
			N (%)	P (%)	K (m.e.)	Ca (m.e.)	Mg (m.e.)
Control	7.3	0.51	1.74	0.098	52.2	27.9	6.3
P_1K_1	12.9	1.08	1.46	0.198	54.7	26.1	16.8
N_1K_1	11.3	0.85	1.59	0.171	40.8	33.4	17.1
N_1P_1	10.7	0.77	1.59	0.174	50.0	31.8	19.1
$N_1P_1K_1$	11.3	0.77	1.55	0.183	51.3	33.3	15.4
$N_1P_1K_1Ca$	7.0	0.40	1.59	0.163	41.4	41.3	11.6
$N_1P_1K_1CaMg$	11.5	0.75	1.50	0.202	42.6	41.2	10.7

Table 11

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

Source of variation	Degrees of freedom	Sum of squares	Mean square	Observed F value	$F_{.05}$ value	$F_{.01}$ value
Total	27	163.93				
Treatments	6	111.70	18.62	7.48**	2.57	3.81
Pots having same treatment	21	52.23	2.49			

** Significant at the 1 % level.

Table 12

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

Treatments	Mean height (cm.)	Differences among the mean heights (cm.)					
P_1K_1	12.9	5.9**	5.6**	2.2	1.6	1.6	1.4
$N_1P_1K_1CaMg$	11.5	4.5**	4.2**	0.8	0.2	0.2	
$N_1P_1K_1$	11.3	4.3**	4.0**	0.6	0.0		
N_1K_1	11.3	4.3**	4.0**	0.6			
N_1P_1	10.7	3.7**	3.4**				
Control	7.3	0.3					
$N_1P_1K_1Ca$	7.0						

** Significant at the 1% level.

$\overline{D}_{.05}=2.080\times\sqrt{2.49\times2/4}=2.32$; $\overline{D}_{.01}=2.831\times\sqrt{2.49\times2/4}=3.16$

The productive arable soils in Taiwan respond to nitrogen fertilizer more strikingly than less productive soils (20). It is also true of the China fir forest soils; the seedlings on Chuyunshan soil with nitrogen fertilizer show greater response than the seedlings on Chungkeng soil.

It is worthy of note in this study that the phosphorus level in the needles of seedlings is related to the height increase in pot cultures. With greater growth in height the seedlings accumulated a high percentage of phosphorus in the needles. On the contrary, the seedlings contained low phosphorus content in foliage and the growth was thus depressed. As shown in Tables 8 and 10, the amounts of phosphorus in the needles of seedlings on Chungkeng soil with N_1K_1, N_1P_1 and the control, as well as in the foliage of those on Chuyunshan soil with $N_1P_1K_1Ca$ and the control are relatively lower than those in needles of seedlings grown on the same soil with other treatments; their mean heights are smaller as well.

4. Fertility standards for growth of China fir seedlings.

After making a comparative and detailed study of all the factors concerned with the fertility of China fir forest and nursery soils, fertility standards for raising this species in the nursery may be made as shown in Table 13. With slight modifications the mean values for various factors concerned with the fertility of China fir forest soils may be adapted as standards for the maintenance of fertility of nursery soils. The growing season is long for China fir seedlings in nurseries in Taiwan. If other factors and the fertility of nursery soils are adequate, strong and plantable size seedlings will be expected at the end of one growing season. Nurserymen generally desire to have 1-0 plantable China fir seedlings. This is not only to shorten the time for growing this species in the nursery but also to lower the cost. Therefore, it is reasonable to believe that the fertility standards will meet the requirements of China fir seedlings in nurseries though the levels of total nitrogen, available phosphorus and cation exchange capacity listed in Table 13 are higher than the standards for conifers with Wilde (14).

Table 13

Fertility standards for raising China fir seedlings in forest nurseries

Soil reaction (pH)	Total N (%)	Available P		Exchange-able K (m.e.)	Exchange-able Ca (m.e.)	Exchange-able Mg (m.e.)	Cation exchange capacity (m.e.)
		(%)	lb./A.				
5.2	0.27	0.002	40	0.40	4.5	1.5	20

One of the important aspects of the reaction of nursery soils is its effect on parasitic fungi which attack the roots of seedlings. Severity of damping-off disease of China fir seedlings in some nurseries in Taiwan has been investigated (18). A desirable reaction range of nursery soils between pH 5 and 5.5 has been suggested for most coniferous species (14). In the present study the mean values for the reaction of the China fir forest soils and for that of the nursery soils were at the same point pH 5.2. It is wise to keep the reaction of nursery soils for growing China fir seedlings at this criterion to avoid attack from damping-off disease.

The nursery soils studied were mostly low in organic matter. The low content of organic matter in soils may be the main cause of their low productivity. Furthermore, the fact that productive soils respond to fertilizers more strikingly than less productive soils has been confirmed by the fertilizer tests in the present study. In fact, 1-0 Jack pine seedlings grown on the soil with NPK fertilizers plus peat show higher survival percentage after planting in the field than the seedlings on the soil with NPK fertilizers alone (14). It is suggested to use green manure and stable manure along with chemical fertilizers for the maintenance of fertility of nursery soil up to the standard levels so as to raise the productivity of the soil.

SUMMARY

Soil and foliar analyses as well as fertilizer tests were used for the study of the fertility of China fir forest and nursery soils. Fifty seven samples each of soil and of China fir tree needles were collected from the China fir forest lands; nine samples each of soil and of the needles of China fir seedlings were collected from the nurseries. Soil was analysed for pH value, 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 means for the contents of organic matter, total nitrogen, exchangeable potassium and cation exchange capacity in the forest soils are significantly greater than those for these factors in the nursery soils. The carbon-nitrogen ratio of the organic matter in the forest soils ranges from 5.9-13.7, and the mean is 8.3. A linear correlation is found between the content of available phosphorus in the forest soils and the pH values. Total nitrogen and cation exchange capacity in both the forest and nursery soils are significantly correlated with the content of organic matter. The correlation between the amounts of exchangeable potassium and magnesium in the forest soils and the cation exchange capacity are found to be linear and significant.

The means for the contents of calcium and magnesium in the China fir tree leaves show significant differences from those for these elements in the seedlings on the nursery soils. The contents of nitrogen and phosphorus in the needles of China fir trees are linearly cerrelated with statistical significance with the levels of total nitrogen and available phosphorus found in the forest surface soils. These relationships indicate that these elements, especially available phosphorus, may be limiting China fir growth on less productive soils.

The seedlings grown on Chuyunshan soils responded significantly with the fertilizer applications. However, no response for the seedlings on Chungkeng soils was found. The phosphorus concentration in the needles of seedlings is related to their growth in height in pot cultures. With greater height increase, the needles accumulate a higher percentage of phosphorus. Contrarily, a lesser amount of phcsphorus in the depressed seedlings is observed.

Fertility standards for maintenance of the fertility of nursery soils for raising China fir seedlings are suggested.

LITERATURE CITED

1. Chen, Hsien-fang, 1963. Fertility standards for growth cf Cryptomeria seedlings based on a study of forest and nursery soils. (In press).
2. Gessel, S. P., 1962. Progress and problems in mineral nutrition of forest trees. In "Tree growth" (Ed. by T. T. Kozlowski), pp 221-235. The Ronald Press.
3. Hibbard, P. L., and P. B. Stout, 1933. The estimation of potassium by titration of the cobaltinitrite with potassium permanganate. Jour. Assoc. Off. Agr. Chem. 16: 137-140
4. Kolthoff, I. M., and R. B. Sandell, 1938. Textbook of quantitative inorganic analysis: The determination of calcium. MacMillan Co., pp 576-577.

5. Leyton, L., and K. A. Armson, 1955. Mineral composition of the foliage in relation to the growth of Scots pine. For. Sci. 1:210-218.
6. Mitchell, H. L., and R. F. Chandler, Jr., 1939. The nitrogen nutrition and growth of certain deciduous trees of Northestern United States. With a discussion of the principles and practice of leaf analysis as applied to forest trees. Black Rock Forest Bul. 11. 94 pp.
7. Murry, W. H., Jr., and S. E. Q. Ashley, 1938. Determination of manganese, nickel, and phosphorus in iron and steel. Ind. and Eng. Chem. (Anal. Ed.) 10:1-5.
8. Peech, M., L. T. Alexander, L. A. Dean, and J. F. Reed, 1947. Methods of soil analysis for soil fertility investigations. U.S.D.A. Circ. 757.
9. Piper, C. S., 1950. Soil and plant analysis. Interscience Publishers. Inc., N. Y.
10. Tamm, C. O., 1954. A study of forest nutrition by means of foliar analysis. In "Plant analysis and fertilizer problems", pp 203-207. I.R.H.O., Paris.
11. Thomson, G. W., and A. L. McComb, 1962. Growth of plantation black walnut in relation to pH and certain chemical factors of the soil. For. Sci. 8: 322-333.
12. Truog, E., 1930. The determination of readily available phosphorus of soils. Amer. Soc. Agron. Jour. 22 : 874-882.
13. Wilde, S. A., 1938. Soil fertility standards for growing northern conifers in forest nurseries. Jour. Agric. Res. 57 : 945-952.
14. Wide, S. A., 1958. Forest soils. The Ronald Press.
15. Wilde, S. A., and J. C. Kopitke, 1940. Base exchange properties of nursery soils and the application of potash fertilizers. Jour. For. 38: 330-332.
16. Wilde, S. A., and W. E. Patzer, 1940. Soil fertility standards for growing northern hardwoods in forest nurseries. Jour. Agric. Res. 61: 215-221.
17. Youngberg, C. T., and R. C. Austin, 1954. Fertility standards for raising Douglas fir in forest nurseries. Jour. For. 52:4-6.
18. 王子定，郭寶章，1960. 臺灣之經濟樹木 I. 臺灣大學農學院實驗林印行.
19. 茹皆耀，華孟，1947. 臺中縣之土壤. 臺灣省農業試驗所專報第六號.
20. 張守敬，1951. 臺灣省土壤肥力概述，（湯元吉主編，臺灣省土壤調查及肥力測定報告書). 臺灣肥料公司叢刊第五種.

NATIONAL CENTRAL LIBRARY

培育杉木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，探討杉木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杉木苗之用。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。

杉木林土壤及林木針葉各五十七個樣本，苗圃土壤及杉木苗針葉各九個樣本，以及肥料試驗培育之幼苗針葉，均作化學分析，以觀察不同土壤之肥力變化，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。針葉分析之項目有：氮、磷、鉀、鈣、及鎂等養分元素。

杉木林土壤及苗圃土壤經化學分析結果，顯示林地土壤各肥力因子之平均值均較苗圃者爲高，其中以有機物、全氮量、交換性鉀、及陽離子交換量等項比較顯著。

杉木林土壤各肥力因子間之關係有：土壤有機物之碳氮比幅度爲 5.9～13.7，平均值爲 8.3。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顯著性正相關，交換性鉀及交換性鎂亦分別與陽離子交換量成顯著性正相關。至於苗圃土壤方面，則有全氮量及陽離子交換量分別與有機物成顯著性正相關。

林木針葉各養分元素之平均值除鈣素外均比較幼苗者高，其中以鎂素較顯著。但幼苗之鈣素平均值則高出林木者甚多。

針葉養分量與土壤養分量間之關係，經發現者有林木針葉之氮磷兩元素分別與林地表土之全氮量及有效性磷成顯著性之正相關。此種相關顯示在肥力較低之杉木林土壤，此兩元素之有效量可能限制杉木之生長，其中以有效性磷之影響較大。

生長於出雲山土壤之盆栽杉木苗對施用之肥料有極顯著之反應，而生長於中坑土壤者則無顯著反應。盆栽幼苗針葉化學分析結果顯示一種趨勢，即針葉含磷量高者幼苗之生長亦高，生長矮小之幼苗其所含之磷量亦較低。

杉木林土壤各肥力因子之平均值經稍予修改後採爲肥力標準，可用以培育杉木苗。玆將各值列表如下：

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	0.27	0.002	40	0.40	4.5	1.5	20

臺灣各苗圃培育杉木苗常遭猝倒病爲害。引起杉木苗猝倒病之因子甚多，苗床土壤反應之 pH 值過高乃其中主要因子之一。因此，苗床土壤反應以保持在 pH 5.2 左右爲佳。再者，本研究所用之苗圃土壤，有機物含量均少，生產力亦低。維持苗圃土壤肥力宜併用有機堆肥（或腐植質）及化學肥料。此不獨提高土壤生產力，保持良好土壤理化性質，亦可增加幼苗之成活潛力。