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Studies on Fertilizer-Managements and Growth Analysis in the Rejuvenating Bamboo Grove*[1]

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回復途上에 있는 참대林의 肥培와 生長解析에 関한 研究*[1]

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ABSTRACT

The growth characteristics and appropriate fertilizer-managements in the rejuvenating bamboo grove were studied with *Phyllostachys reticulata.* The bamboo soil was the sandy loam with rich humus. In the fertilized plots, the N-fertilizer was significantly absorbed, and it was necessary to fertilize the K-fertilizer continuously. According to the development of rejuvenating after flowering, the temperature and relative illumination became lower, while the moisture became higher. The relationship between the diameter at eye height (D) and the culm length (H) of each bamboo can be expressed as follow; $H = 2.5538D^{0.5031}$ The leaf area is the major factor for the production of the bamboo grove. Therefore in the rejuvenating grove, we should refrain from pruning or felling of not-flowering bamboo. The theoretical distribution of the internodal length was obtained by the distribution curve line of the internodal length derived from the regular distribution curve line. Relatively long and even internodal length was found in the fertilized plots 2 and 4. The relation between D^2H and dry weight of culm or dry weight of the above ground part were given by linear regression in both relations respectively on the logarithmic coordinates, but the proportional relation was not established in these relations. The biomass of the above ground part obtained by the allometry method showed high values in the fertilized plots 2, 5 and 6. The appropriate amounts of the three elements, N, P and K for the maximum dry matter were 24.19, 15.51, 8.63 Kg/10a, respectively.

Key words: Phyllostachys reticulata; fertilizer-managements; biomass.

要 約

참대를 材料로 하여 開花後 回復途上에 있는 竹林의 生長特性과 合理的인 비배에 関하여 해석하였다. 試験地 竹林 土壌은 부식질이 풍부한 사양토였으나 施肥区에서는 無肥区에 비하여 질소질 肥料의 흡수가 현저하게 왕성하였으며, 가리질 肥料의 계속적인 施肥가 必要한 상태였다. 開花後 回復이 촉진됨에 따라 竹林의 온도와 相対照度는 낮아지는 反面 湿度는 높아졌다. 참대의 목통직경 (D)와 幹長(H)과는 $H=2.5538D^{0.5031}$인 関係式으로 나타낼 수 있으며 竹林의 葉面積은 竹林의 生産力을 규제하는 要因이 되고 있으므로 비개화죽의 가지치기나 벌채는 지양하여야 할 것이다. 정규분포곡선식에서 유도한 마디길이 分布曲線式으로 各 마디의 위치별 길이의 理論的인 分布状態를 얻을 수 있다. 施肥 2区와 4区는 비교적 길고 고른 마디길이를 가진 대나무가 많았다. 참대의 D^2H 와 줄기의 건물중, 그리고 D^2H와 地上部 건물중과의 関係는 대수그래프상에서 직선회귀를 나타냈으나 이들 사이에 비례관계는 성립되지 않았다. 相対生長法에 依하여 推定된 대나무 地上部의 現存量은 施肥 2, 5, 6区에서 높은 치를 보였다. 最大乾物量을 얻을 수 있는 N, P, K요소의 적정 施肥量은 各各 24.20, 15.51, 8.63kg/10a였다.

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INTRODUCTION

Bamboo grove is a forest that forms a simple community. It shows the growth characteristics of propagation by rhizome and provides an interesting field of study in the respect of the physiological ecology. Little study has been done on the environmental factors and the dry matter productivity of bamboo stand or on the acceleration of the rejuvenation process after flowering.

According to the study by Ueda *et al.* (1961) on the proper treatment of the bamboo grove after flowering, it is effective to protect the newly grown bamboo and fertilize them with 37.5Kg/10a nitrogen fertilizer during July—August. They claim that we can expect the effect of the phosphoric fertilizer if we continue fertilizing them for 2 or 3 years. Ueda *et al.* (1961) report that the most effective season of applying fertilizers to the Phyllostachys reticulata is March—August. They also report an increase of growth with the mixture of the N, P, K and the calcium silicate acid.

Watanabe *et al.* (1976) analyzed the structure of the *Phyllostachys reticulata* stand by the allometric method and examined the linear regression based on D^2H, the biomas and the apparent density of the dry organic matter. Hsuing Wengue *et al.* (1981) reported that the process of rejuvenation of rhizomes transplanted from the flowering bamboo grove was improved by the GA_3 dip treatment.

The present study was made to analyze the environmental factors and the growth characteristics of the *Phyllostachys reticulata* grove and to establish the appropriate fertilizing method. The results obtained from this study may contribute to the improvement of the cultivation method of rejuvenation.

MATERIALS AND METHODS

The present experiment was carried out on the bamboo grove (owner: Mr. Byung-Jin Woo) located in Daebang-ri, Subook-myun, Damyang-kun, Chunnam-do, Korea, during the period from June 1980 to Dec. 1981. The experimental field was prepared by the randomized block design method on July 7, 1979. The area of each plot was 9 square meters. The treatment of the three fertilizer elements (N-P-K, Kg/10a) were as follows:

Controlled plot (no-fertilizer)
Fertilizer plot 1 (12-15-13)
Fertilizer plot 2 (23-15-13)
Fertilizer plot 3 (35-15-13)
Fertilizer plot 4 (23- 7-13)
Fertilizer plot 5 (23-22-13)
Fertilizer plot 6 (23-15- 6)
Fertilizer plot 7 (23-15-19)

As fertilizers, urea, fused phosphate and potassium chloride were used. These were totally base-applied twice (August 7, 1979 and August 9, 1980). The number of the terrestrial culms were controlled not to per 40-42. Between the plots a ditch (40Cm wide and 40Cm deep) was digged and every rhizome was completely disconnected. The soil sample was randomly obtained from each of the plots. The pH of the soil was measured by the electroglass method and other elements were analyzed as follows: T-N by the microkjeldahal method: O.M. by the Turin's method: Av-P_2O_5 by the Lancaster's method: K_2O and Na_2O by the flame spectrophotometer method: MgO and CaO by the E.D.T.A. method: finally C.E.C. by the Brown's method. Five bamboo samples for the analysis of the chemical components were randomly chosen from each plot and analyzed by the same method as above.

The temperature of the bamboo grove was measured with a thernometer, calibrated according as the standard thernometer, the head of which was wrapped with white paper to keep the ultra violet ray away. The moisture was measured with hygrometer. A relative illumino-meter was used to measure the illumination in order to examine the vertical distribution of the ray of light in the grove. The growth condition was examined twice: August 5-10, 1980 and August 9-14, 1981. The drawing method was applied to measure the leaf area. As for the examination of the dry matter, 5 to 10 terrestrial culms were randomly chosen from each of the plots. Each organ was isolated and dried in a drying oven of 80°C until it reached the constant weight. After that, with a chemical balance they were weighted.

RESULTS AND DISCUSSION

1. Soil conditions in experimental field

In the experimental fields, to the depth of

20-30Cm below the ground, we located the sand loam which shows the following element ratio: gravel -14.7%; coarse sand -24.0% and clay -36.7%. This is a good condition for the cultivation of the *Phyllostachys reticulata.* As shown in Table 1, it was not the case that the plants lacked any organic or available nutritions substance after 5 years of negligence. In the first year of the fertilization, each fertilized plot showed that it absorbed the N-fertilizer more than the controlled plot. In the second fertilizing year, it showed a relatively high value of the remaining T-N. This can be attributed to the result of the continued manure of the N-fertilizer for two years and the active decomposition of the organic substance. As we see in the result of the plant analysis the fertilized plots showed the high T-N value and the value of the content of each plant in comparison with the controlled plot (Table 2). This fact shows an active absorption of the N-fertilizer in the fertilized plot. In each fertilized plot, the remaining amount of the available phosphate increased depending on the number and amount of the fertilizations. This phenomenon may be attributed to the continued use of fused phosphate. The exchangeable Ca and Mg seemed to be a fair condition for the cultivation of the *Phyllostachy reticulata.* K, however, need to be fiertilized every year.

According to a report by the Japan Resource Bureau, the soil producing good bamboos shows the pH value of 5.5-6.0. This proves the importance of

Table 1. Chemical propeties of the soil in the experimental field

Plot	Year	pH	O.M %	T-N	C/N	Av-P_2O_5	Ex-me/100g KCa	Mg	
	1979	5.00	3.52	0.306	6.67	87.8	0.68	2.86	1.55
Cont.	1980	5.32	4.84	0.280	10.02	103.0	0.57	2.60	1.40
	1981	4.95	4.38	0.384	6.62	125.63	0.36	3.30	1.17
	1979	5.0	3.12	0.321	4.30	101.80	1.02	3.56	1.17
Fert. 1	1980	5.53	4.62	0.240	11.16	117.0	0.32	3.40	1.45
	1981	5.30	3.26	0.368	5.14	285.15	0.33	4.54	1.29
	1979	5.60	2.83	0.334	4.91	234.00	0.92	5.42	2.24
Fert. 2	1980	5.30	4.29	0.185	13.45	248.00	0.48	4.40	1.10
	1981	5.44	3.82	0.240	9.23	261.35	0.43	4.23	0.80
	1979	5.30	3.60	0.410	5.09	209.4	0.71	4.42	1.98
Fert. 3	1980	5.40	4.27	0.240	9.17	218.0	0.68	3.1	1.25
	1981	5.35	3.82	0.297	7.46	220.10	0.57	4.46	1.66
	1979	4.90	3.17	0.378	4.86	99.40	0.75	3.56	1.28
Fert. 4	1980	5.30	5.00	0.240	12.08	156.0	0.64	3.30	1.23
	1981	5.23	4.28	0.380	6.53	287.0	0.38	3.38	0.74
	1979	5.3	3.83	0.292	7.60	152.30	0.59	5.12	2.47
Fert. 5	1980	5.40	4.93	0.240	11.91	350.0	0.48	4.40	1.25
	1981	5.28	3.33	0.294	6.60	396.96	0.46	4.64	1.54
	1979	5.50	4.24	0.380	6.47	165.10	0.50	5.38	2.65
Fert. 6	1980	5.53	4.93	0.270	10.59	243.5	0.45	4.20	2.20
	1981	5.31	3.48	0.347	5.82	246.78	0.34	4.44	2.35
	1979	5.40	3.07	0.383	4.65	60.9	0.74	4.24	2.28
Fert. 7	1980	5.50	4.69	0.210	12.95	86.0	0.71	3.80	1.40
	1981	5.36	3.80	0.338	6.52	81.11	0.68	5.33	2.33

Table 2. Chemical components of *Phyllostachys reticulata*

Plot	T-N (%)	AV-P_2O_5 (%)	Exchangeable (%)			
			K	Na	Ca	Mg
Cont.	2.562	1.09	1.10	0.02	0.98	0.34
Fert. 1	2.702	0.89	1.15	0.02	0.86	0.30
Fert. 2	2.702	0.96	1.05	0.01	0.97	0.15
Fert. 3	2.646	0.82	0.90	0.02	0.89	0.37
Fert. 4	2.842	0.96	1.08	0.02	0.82	0.37
Fert. 5	2.716	0.89	1.15	0.02	0.93	0.39
Fert. 6	2.408	1.17	1.20	0.02	0.80	0.32
Fert. 7	2.772	1.09	1.10	0.04	0.80	0.32

Table 3. Culm length of *Phyllostachys reticulata* growing in each treatment plot

Plot	Culm length					
	Yearling measured in 1980			Yearling measured in 1981		
	Range	Mean S.E.	C.V.	Range	Mean S.E.	C.V.
Cont.	328.2-554.0	403.22±20.52	0.16	399.4-568.3	460.62±25.55	0.12
Fert. 1	228.2-491.9	370.65±22.97	0.20	441.4-658.1	578.13±20.74	0.11
Fert. 2	411.6-534.4	461.97±13.24	0.09	453.9-691.0	609.57±22.04	0.11
Fert. 3	402.1-518.6	458.34±14.21	0.10	493.8-644.0	583.24±16.64	0.09
Fert. 4	422.3-570.5	490.24±15.38	0.10	535.7-769.3	607,33±20.19	0.11
Fert. 5	410.3-608.1	497.11±17.93	0.11	409.3-693.9	568.89±25.28	0.14
Fert. 6	405.9-563.5	477.05±14.01	0.19	471.5-673.4	570.29±20.29	0.11
Fert. 7	410.6-546.0	467.23±11.93	0.08	444.8-678.0	549.31±24.44	0.14

the pH value. Compared with the report, the pH value of each experimental plot was low and it was necessary to control the soil acidity to pH 6.0-6.5

2. Temperature, moisture, and relative illumination

The temperature, moisture, and relative illumination of the experimental plots were compared with those of a bamboo grove which is 10 years old after flowering. As shown in Fig. 1, in both bamboo groves, we do not see a significant change of temperature in proportion to the horizontal distance. The compared bamboo grove, however, showed a lower degree of temperature than our experimental plots by 0.5-1.5 °C. The moisture of the compared bamboo grove was higher than our experimental plots by 5.3%-9.8%. The relative illumination measured at the points 1m, 2m and 3m starting from the outside limit of the bamboo grove were 54.5%, 23.5% and 13.5%, respectively. The deeper we pro-

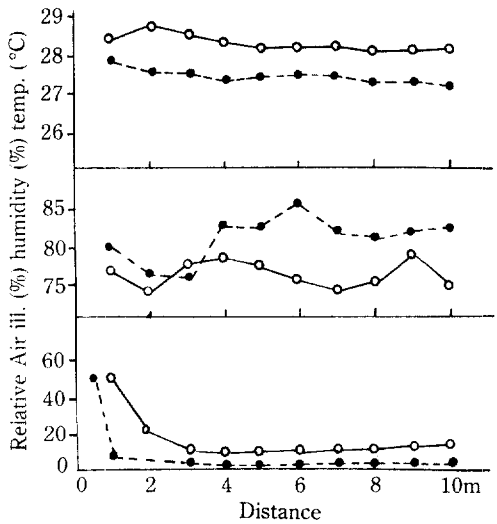

Fig. 1. Climatic conditions by distance in the bamboo grove (o: denotes 10 years old, denotes 6 years old)

ceed into the bamboo grove, the lower the relative illumination became. In the area between 3m and 15m, there was no significant difference of the relative illumination. According to the development of rejuvenation after blooming, the temperature and relative illumination got lowered, while the moisture got a higher percentage. This is an unfavorable condition for the development of the branches. Han & Kim (1977) reported that in an experiment by lowering the light requirement for the growing bamboo sprouts it was possible to gain a 32% increase of the clear length and the number of branches increased by 33%.

3. Growth characteristics of the part above the ground

3.1 In Table 3, 4 the yearling culm length and the diameter at eye height of the *Phyllostachys reticulata*

Table 4. Diameter at eye height of *Phyllostachys reticulata* growing in each treatment plot

Plot	Diameter at eye length per plant					
	Yearling measured in 1980			Yearling measured in 1981		
	Range	Mean S.E.	C.V.	Range	Mean S.E.	C.V.
Cont.	1.15-2.55	1.67±0.13	0.25	0.75-2.45	1.7 ±0.24	0.31
Fert.1	0.60-2.30	1.66±0.13	0.28	1.8 -2.75	2.4 ±0.09	0.02
Fert. 2	1.65-2.45	1.96±0.98	0.16	1.9 -3.2	2.64±0.12	0.14
Fert. 3	1.35-2.50	1.87±0.11	0.19	2.0 -2.75	2.46±0.08	0.10
Fert. 4	1.75-2.75	2.17±0.08	0.12	2.2 -3.4	2.58±0.10	0.13
Fert. 5	1.05-2.95	1.86±0.16	0.27	1.0 -3.0	2.33±0.17	0.13
Fert. 6	1.50-2.55	1.97±0.10	0.16	1.95-3.1	2.41±0.11	0.14
Fert. 7	1.50-2.45	2.02±0.09	0.14	1.8 -2.7	2.29±0.10	0.13

Table 5. Test of the significance between replications and between the means of culm length, diameter at eye height, clear length and branched number of *Phyllostachys reticulata*.

Year \ Year		1980								1981							
Culm	plot	5	4	6	7	2	3	c	1	4	2	3	1	6	5	7	c
length	mean	479.11	490.24	477.05	467.33	461.97	458.34	403.22	370.65	617.33	609.57	578.55	578.12	570.29	556.30	531.66	464.42
LSD (0.05)		49. 544 (between 10 and 10)								63.564 (between 10 and 10) 86.105 (between 10 and 5)				68.707 (between 10 and 9) 87.324 (between 9 and 5)			
Diameter	plot	4	7	6	2	3	5	c	1	3	4	2	1	5	7	6	c
at eye length	mean	2.17	2.02	1.97	1.96	1.87	1.86	1.67	1.46	2.73	2.57	2.53	2.49	2.38	2.28	2.27	1.94
LSD (0.05)		0.345 (between 10 and 10)								0.360 (between 10 and 10) 0.388 (between 10 and 9)				0.434 (between 10 and 5) 0.494 (between 9 and 5)			
Clear	plot	5	6	7	4	2	3	c	1	2	7	4	5	6	3	1	c
length	mean	178.10	130.30	129.20	98.40	97.50	86.50	77.20	64.29	272.38	261.83	238.19	230.07	211.87	206.22	204.20	166.76
LSD (0.05)		35.358 (between 10 and 10)								58.417 (between 10 and 10) 60.017 (between 10 and 9)				71.546 (between 10 and 5) 72.859 (between 9 and 5)			
Branched	plot	4	2	3	7	6	c	1	5	6	4	3	2	1	5	7	c
number	mean	55.4	49.9	49.4	49.4	48.5	48.0	46.6	43.2	47.5	46.7	45.8	45.6	42.6	42.2	39.45	36.8
LSD (0.05)		6.330 (between 10 and 10)								4.826 (between 10 and 10) 4.958 (between 10 and 9)				5.965 (between 10 and 5) 6.019 (between 9 and 5)			
Culm	plot	4	5	6	2	7	3	c	1	3	4	2	1	5	6	7	c
volume	mean	10.14	8.68	8.21	7.88	7.75	7.22	5.49	3.87	18.36	17.87	17.75	15.94	13.65	12.82	12.69	9.00
LSD (0.05)		3.360 (between 10 and 10)								5.775 (between 10 and 10) 6.252 (between 10 and 9)				6.979 (between 10 and 5) 7.933 (between 9 and 5)			

Note; 1) The number in parenthesis indicate the number of replication.
2) In 1980, 10 replication each plot, in 1981, 5 replication for control plot, 9 replication for fert. 7, and 10 replication for fert. 1, 2, 3, 4, 5 and 6.

were shown according to each treatment plot. As for the culm length and the diameter at eye height, the mean values of the controlled plot and each fertilized plot showed significant difference (Table 5). Depending on the sprouting of the newly grown culms, the leading mean value of the experimental plots were different.

For each plot, we plotted the value of the diameter at eye height D and the value of the culm length H of each plot, on the log-log scale graph paper. The result formed a straight line and the equation can be written as follows:

$$H = 2.553D^{0.5031}$$

That is, the relationship between log D and log H of each bamboo-regardless of the difference of age, amount of fertilizer, density of the bamboo grove could be shown in a straight line. (Fig. 2). This

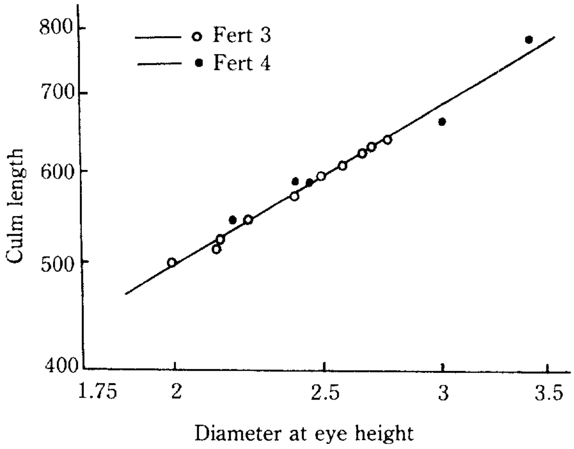

Fig. 2. Relation between length of terrestrial culm and diameter at eye height in two bamboo groves.

Table 6. Clear length of *Phyllostachys reticulata* growing in each treatment plot

Plot	Clear length per plant					
	Yearling measured in 1980			Yearling measured in 1981		
	Range	Mean S.E.	C.V.	Range	Mean S.E.	C.V.
Cont.	12-168	77.20±14.33	0.58	114-237.2	166.76±20.81	0.28
Fert. 1	27-150	84.25±10.30	0.51	153-280.8	204.20±17.36	0.27
Fert. 2	79-143	97.50± 6.31	0.20	135-375	272.38±21.26	0.25
Fert. 3	28-138	86.50±11.77	0.43	77-300	206.22±22.43	0.34
Fert. 4	51-142	98.40±10.08	0.32	70-351.2	238.19±26.87	0.36
Fert. 5	132-214	178.10± 8.21	0.14	117.2-321.8	230.07±17.44	0.24
Fert. 6	60-258	130.3 ±17.00	0.41	143-334.5	211.87±18.88	0.28
Fert. 7	44-195	129.2 ±13.55	0.33	208-315	261.83±10.25	0.12

Table 7. Branched number of *Phyllostachys reticulata* growing in each treatment plot

Plot	Branched number per plant Plot					
	Yearling measured in 1980			Yearling measured in 1981		
	Range	Mean S.E.	C.V.	Range	Mean S.E.	C.V.
Cont.	42-60	46 ±1.92	0.13	26-49	36.8±4.22	0.26
Fert. 1	40-55	46.6±1.37	0.09	33-55	42.6±2.06	0.14
Fert. 2	44-59	49.9±1.46	0.09	39-49	45.6±1.02	0.07
Fert. 3	43-60	49.4±1.72	0.11	38-57	45.8±2.04	0.14
Fert. 4	47-60	55.4±1.36	0.07	37-63	46.7±2.41	0.16
Fert. 5	30-55	43.2±2.46	0.18	29-49	42.2±1.88	0.14
Fert. 6	43-57	48.5±1.30	0.08	37-57	47.5±1.96	0.13
Fert. 7	45-54	49.4±0.92	0.05	28-56	39.45±2.75	0.21

Table 8. The relation dry weight of leaves and dry weight of the part above ground of *Phyllostachys reticulata* in each treatment plot

Plot	Regression analysis Y	Correlation r
Cont.	0.2059x − 14.5209	0.9923
Fert. 1	0.2111x + 175.9069	0.9714
Fert. 2	0.1794x + 267.2296	0.8675
Fert. 3	0.1794x + 267.2280	0.8675
Fert. 4	0.2160x + 196.1943	0.9647
Fert. 5	0.2365x + 125.9077	0.9883
Fert. 6	0.1572x + 300.3860	0.9874
Fert. 7	0.2583x + 115.2168	0.9101

can be regarded as a characteristic disposition of the *Phyllostachys reticulata.* Watanabe (1976) also reported a similar result.

3.2 Clear length and Branched number.

As shown in Tables 6 and 7 in all the fertilized plots the clear length was longer than that in the controlled plot. In the first year the average clear length of the fertilized plot 5 was high and from the second year on that of the second plot was high. As for the branches, in the first year the second plot showed a high number and from the second year on the sixth plot showed a high number. In other words, not only in the clear length but in the branched number, the significance between each plot does not show a fixed tendency (Table 5).

3.3 Leaf area.

As shown in Table 11, the leaf area value of the controlled plot was remarkably low than the fertilized plots. The highest value was 2980.01cm^2 per plant in the second fertilized plot. Between the leaf area and the dry matter there appeared a high significance of a positive relationship (Table 8). According to Watson's (1958), LAI (leaf area index) is more important than the photosynthetic capacity of the leaves in the material production of the terrestrial plants. Donald (1958) also claim that the primary factor of the maximum material productivity of the a plant community is the most appropriate leaf area. The leaf area privides the conditions that control the assimilatory production of the bamboo grove. It decreases the light requirement and controls the temperature and humidity of the bamboo grove. Thus, it restricts the development of the branches of the newly grown bamboo. Like this the leaf area is

Table 9. Distribution of internodal length

Plot	Year	Height	Diameter at eye height	Total nodes (N)	Node position Long (Nl)	Node position control (Nc)	Average (N)	S.D. (δ)	$\frac{\delta}{N}$
Cont.	1980	436.1	2.05	35	9	17	14	4.29	0.34
	1981	445.2	2.10	30	12	15	14	7.58	0.5
Fert. 1	1980	360.9	1.45	31	11	16	13	4.72	0.41
	1981	576.9	2.15	37	13	19	16	7.04	0.45
Fert. 2	1980	461.4	1.75	32	11	16	14	6.77	0.47
	1981	611.1	2.45	39	14	18	16	7.44	0.48
Fert. 3	1980	499.2	2.05	36	13	18	15	5.84	0.42
	1981	632.2	2.70	36	14	18	16	8.84	0.5
Fert. 4	1980	499.3	2.15	36	9	17	14	6.67	0.48
	1981	607.6	2.50	39	14	18	16	7.81	0.5
Fert. 5	1980	485.9	1.85	34	11	17	14	6.33	0.44
	1981	548.3	2.10	37	13	18	15	7.02	0.47
Fert. 6	1980	468.5	1.85	36	13	18	15	5.71	0.44
	1981	552.0	2.15	37	12	18	15	6.25	0.42
Fert. 7	1980	464.2	1.95	34	12	17	14	6.58	0.48
	1981	534.0	2.10	34	12	17	14	8.07	0.5

Table 10. Distribution of internodal length of the culm per plant of *Phyllostachys reticulata* under controlled and fertilized plot.

Age	Plot	Year	H	$\bar{N}$	Equation
Yearling	Control	1980	H = 436.1cm,	$\bar{N}$ = 14	$h_0 = \frac{436.1}{1.25 \times 14} e^{-2}(\frac{N}{14} - 1)^2 = 24.92e^{-2}(\frac{N}{14} - 1)^2$
		1981	H = 445.2cm,	$\bar{N}$ = 14	$h_0 = \frac{445.2}{1.25 \times 14} e^{-2}(\frac{N}{14} - 1)^2 = 25.44e^{-2}(\frac{N}{14} - 1)^2$
	Fert. 1	1980	H = 360.9cm,	$\bar{N}$ = 13	$h_1 = \frac{360.9}{1.25 \times 13} e^{-2}(\frac{N}{13} - 1)^2 = 22.21e^{-2}(\frac{N}{13} - 1)^2$
		1981	H = 576.9cm,	$\bar{N}$ = 16	$h_1 = \frac{576.9}{1.25 \times 16} e^{-2}(\frac{N}{16} - 1)^2 = 28.84e^{-2}(\frac{N}{16} - 1)^2$
	Fert. 2	1980	H = 461.4cm,	$\bar{N}$ = 14	$h_2 = \frac{461.4}{1.25 \times 14} e^{-2}(\frac{N}{14} - 1)^2 = 26.37e^{-2}(\frac{N}{14} - 1)^2$
		1981	H = 611.1cm,	$\bar{N}$ = 16	$h_2 = \frac{611.1}{1.25 \times 16} e^{-2}(\frac{N}{16} - 1)^2 = 30.56e^{-2}(\frac{N}{16} - 1)^2$
	Fert. 3	1980	H = 499.2cm,	$\bar{N}$ = 15	$h_3 = \frac{499.2}{1.25 \times 15} e^{-2}(\frac{N}{15} - 1)^2 = 26.62e^{-2}(\frac{N}{15} - 1)^2$
		1981	H = 632.2cm,	$\bar{N}$ = 16	$h_3 = \frac{632.2}{1.25 \times 16} e^{-2}(\frac{N}{16} - 1)^2 = 31.61e^{-2}(\frac{N}{16} - 1)^2$
	Fert. 4	1980	H = 499.3cm,	$\bar{N}$ = 14	$h_4 = \frac{499.3}{1.25 \times 14} e^{-2}(\frac{N}{14} - 1)^2 = 28.53e^{-2}(\frac{N}{14} - 1)^2$
		1981	H = 607.6cm,	$\bar{N}$ = 16	$h_4 = \frac{607.6}{1.25 \times 16} e^{-2}(\frac{N}{16} - 1)^2 = 30.83e^{-2}(\frac{N}{16} - 1)^2$
	Fert. 5	1980	H = 485.9cm,	$\bar{N}$ = 14	$h_5 = \frac{485.9}{1.25 \times 14} e^{-2}(\frac{N}{14} - 1)^2 = 27.77e^{-2}(\frac{N}{14} - 1)^2$
		1981	H = 548.3cm,	$\bar{N}$ = 15	$h_5 = \frac{548.3}{1.25 \times 15} e^{-2}(\frac{N}{15} - 1)^2 = 29.24e^{-2}(\frac{N}{15} - 1)^2$
	Fert. 6	1980	H = 468.5cm,	$\bar{N}$ = 15	$h_6 = \frac{468.5}{1.25 \times 15} e^{-2}(\frac{N}{15} - 1)^2 = 24.99e^{-2}(\frac{N}{15} - 1)^2$
		1981	H = 552.0cm,	$\bar{N}$ = 15	$h_6 = \frac{552.0}{1.25 \times 15} e^{-2}(\frac{N}{15} - 1)^2 = 29.44e^{-2}(\frac{N}{15} - 1)^2$
	Fert. 7	1980	H = 464.2cm,	$\bar{N}$ = 14	$h_7 = \frac{464.2}{1.25 \times 14} e^{-2}(\frac{N}{14} - 1)^2 = 26.53e^{-2}(\frac{N}{14} - 1)^2$
		1981	H = 534.0cm,	$\bar{N}$ = 14	$h_7 = \frac{534.0}{1.25 \times 14} e^{-2}(\frac{N}{14} - 1)^2 = 30.51e^{-2}(\frac{N}{14} - 1)^2$

the major factor for the production of the bamboo grove. Therefore, in the rejuvenating bamboo grove we should refrain from pruning or felling of non flowering bamboo. A similar result was reported in Ueda (1960).

3.4 Distribution of Internodal Length

The internodal length of bamboo usually reaches its maximum around the center nodal position and then gradually decreases toward both ends in a more or less symetrical form. Thus, the internodal length can be expressed by the normal distribution equation.

$$y = \frac{1}{\delta\sqrt{2\pi}}\ e - \frac{(x-\bar{x})^2}{2\delta^2} \cdots (1)$$

$$h(p) = \frac{1}{\delta\sqrt{2\pi}}\ e - \frac{(N-\bar{N})^2}{2\delta^2} \ldots (2)$$

In the equation, y indicates the length rate h(p) of the individual internodes, x the number of individual node position N, x the average number of nodal position $\bar{N}$, δ the standard deviation of average nodal positions (δ).

In Table 9, the average node position (N) is located between the longest internode $N\ell$ and the central internode (Nc) as usually expressed in $N\ell \leq N \leq Nc$. The deviation coefficient δ/N of bamboo in each plot varies between 0.41-0.49. Such a difference is so small that we can neglect it.

Thus, an assumed constant is $\frac{\delta}{N}$ = 0.5 as used in the practical calculation. The equation(2) can be rewritten as follows:

$$h(p) = \frac{1}{0.5\bar{N}\sqrt{2\pi}}\ e - \frac{(N-\bar{N})^2}{2(0.5\bar{N})^2}$$

$$= \frac{1}{1.25N}\ e^{-2}\left(\frac{N}{\bar{N}} - 1\right)^2 \ldots\ldots (3)$$

Equation(4) is an expression of the internodal length rate of culms and can be used to calculate the actual length(h) of individual internodes by multiplying the internodal length rate by the total height(H) of the culm.

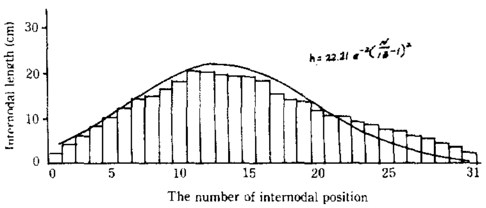

Fig. 3. Internodal length of one year old culm of *Phyllostachys reticulata* under fertilized plot 1.

$$h = h(p) \times H \frac{1}{1.25\bar{N}}\quad e^{-2}\left(\frac{N}{\bar{N}} - 1\right)^2 \quad \ldots. (4)$$

According to above equation (4), the curveline equation of the distributional internodal length of bamboos of each plot can be obtained as a Table 10. With these equations we can have the theoretical distribution of the bamboo's internodal length in each treat-

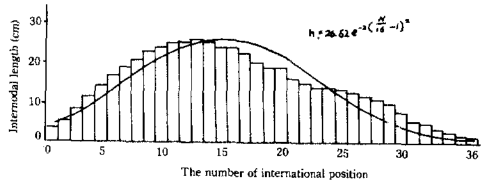

Fig. 4. Internodal length of one year old culm of *Phyllostachys reticulata* under fertilized plot 3.

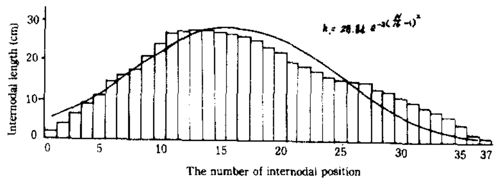

Fig. 5. Internodal length of yearling culm of *Phyllostachys reticulata* under fertilized plot 1.

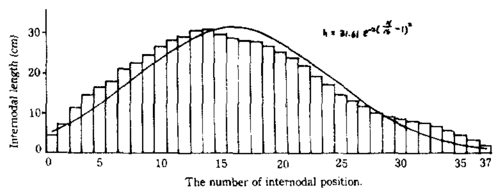

Fig. 6. Internodal length of yearling culm of *Phyllostachys reticulata* under fertilized plot 3.

ment plot. Each fertilized plot, but not in the controlled plot, the internodal length got longer in the second fertilizing year. In the fertilized plot 2 and fertilized plot 4, we could check the noticeable growth of the internodal length in the first and second years. It was also observed that the long internodal length was relatively evenly distributed (Table 10) (Fig. 3, 4, 5, 6). Zhou Fanchun (1981) reported the theoretical distribution of the internodal length by applying the

Table 11. Experimental results on the growth of *Phyllostachys reticulata* under fertilized and controlled plot.

Sampling date	Plot	Treatment	No	Dry weight of the part above ground			Total	Leaf area
		N-P-K		Culms	Branches	Leaves		
			1	284.76	89.89	97.21	471.86	2605.22
			2	250.49	80.24	77.38	408.11	2073.78
	Control	0-0-0	3	67.57	20.37	22.82	110.76	611.57
			4	279.31	90.14	75.65	445.10	2027.42
			5	537.79	173.17	157.74	868.70	4227.43
			1	420.35	97.48	193.60	611.43	2776.48
			2	400.12	78.93	81.43	560.48	2174.18
			3	410.43	98.16	93.89	582.48	2516.25
			4	319.16	53.97	67.87	441.00	1818.91
	Fert. 1	12-15-13	5	300.94	43.81	65.95	410.70	1767.46
			6	424.14	95.42	63.29	582.85	1689.84
			7	381.48	89.02	91.90	552.40	2453.73
			8	373.10	68.79	70.16	502.02	1873.27
			9	400.42	114.84	104.00	589.26	2776.68
			10	394.14	78.87	81.37	534.38	2172.58
			1	545.78	121.07	100.33	767.18	2678.81
			2	814.19	162.89	165.83	1142.91	4427.66
			3	807.10	172.90	166.60	1146.60	4448.22
			4	280.82	66.66	47.24	394.72	1261.30
Aug. 8-14, 1981	Fert. 2	23-15-13	5	540.24	124.81	95.00	760.05	2536.5
			6	475.90	96.31	95.45	667.66	2548.51
			7	387.16	86.79	70.56	544.51	1883.95
			8	564.25	150.14	120.58	834.97	3219.48
			9	679.89	162.35	164.39	1006.63	4389.21
			10	600.23	93.84	90.13	784.20	2406.47
			1	386.04	78.38	66.40	530.82	1772.88
			2	486.24	120.20	70.43	676.87	1880.48
			3	560.48	118.85	120.75	800.08	3224.02
			4	664.19	100.74	120.31	885.24	3212.27
	Fert. 3	35-15-13	5	630.10	104.70	144.19	878.99	3849.87
			6	408.41	80.78	66.00	555.19	1762.20
			7	354.97	65.32	65.58	485.87	1750.98
			8	524.97	145.53	115.69	786.19	3088.92
			9	650.44	127.07	100.10	877.61	2672.67
			10	600.12	146.41	102.00	848.53	2723.40
			1	410.80	81.29	70.14	562.23	1872.73
			2	520.97	91.00	88.78	700.75	2370.42
			3	585.34	120.04	110.11	815.49	2939.93
			4	543.24	100.27	98.14	741.65	2620.33
	Fert. 4	23-7-13	5	739.95	152.46	169.87	1062.28	4535.52

Sampling date	Plot	Treatment	No	Dry weight of the part above ground			Total	Leaf area
		N-P-K		Culms	Branches	Leaves		
			6	500.62	120.79	71.02	692.63	1896.23
			7	515.19	100.85	101.14	717.18	2700.43
			8	459.13	105.26	65.12	629.51	1738.70
			9	1005.42	250.10	197.85	1453.37	5282.59
			10	490.94	109.43	85.48	685.85	2282.31
			1	379.98	70.96	62.54	513.48	1669.81
			2	483.14	90.90	77.52	651.56	2069.78
			3	590.90	100.12	107.76	798.78	2877.19
			4	114.27	20.44	18.70	153.41	499.29
	Fert. 5	23-22-13	5	425.89	90.32	68.84	585.05	1838.02
			6	787.12	158.35	161.50	1106.97	4312.05
			7	800.98	129.93	155.82	1086.73	4106.39
			8	500.48	113.10	81.39	694.97	2173.11
			9	520.00	111.63	89.25	720.88	2382.975
			10	350.17	80.26	53.40	483.83	1425.76
			1	340.00	68.53	48.23	456.76	1287.741
			2	580.94	115.22	121.08	817.24	3232.83
			3	664.87	170.75	160.84	996.46	4294.42
			4	355.49	54.45	42.13	452.07	1124.87
Aug. 8-14, 1981	Fert. 6	23-15-6	5	410.29	78.12	61.98	550.39	1654.86
			6	406.50	80.06	70.35	556.91	1878.34
			7	764.94	200.34	220.44	1185.72	5885.74
			8	460.93	85.50	71.18	617.61	1900.50
			9	480.15	88.72	62.39	631.26	1665.81
			10	602.84	143.66	125.74	872.24	3357.25
			1	496.78	106.41	80.63	683.82	2152.82
			2	476.34	80.94	28.28	635.56	2090.07
			3	554.74	140.79	83.86	779.39	2239.06
			4	430.46	98.52	65.64	594.62	1752.58
	Fert. 7	23-15-19	5	596.94	152.75	80.72	830.41	2155.22
			6	634.71	154.98	131.44	921.13	3509.44
			7	289.78	48.76	50.87	389.41	1358.22
			8	339.77	57.28	52.87	449.92	1411.62
			9	270.37	48.15	44.04	362.56	1175.86

regular curveline equation through a study on the structure of culms of the *Phyllostachys pubescens*.

4. Standing crop of the terrestrial stem

Kittredge (1944) discovered that there exist a relation of allometry log Y = h log X. log A between the amount (X) of a part and the amount (Y) of another part in a stand. In this equation, h indicates the coefficient of allometry and A the constant depending on the circumstance of the stand. Since Kittredge's discovery, many ecologists estimated the dry matter production of the stand by applying his principle. Many researches were made by applying the relation of allometry, log D^2H - log Ws, log D^2H - log Wb, log

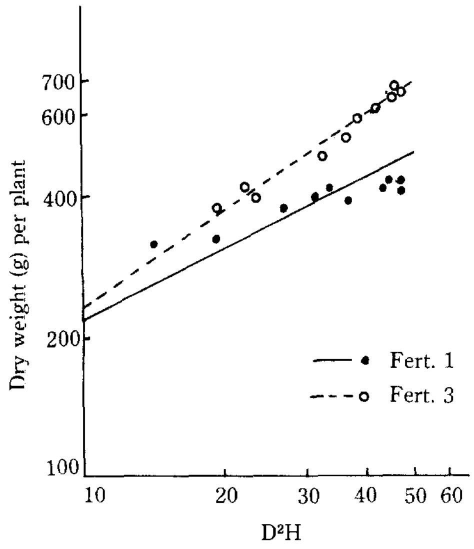

Fig. 7. Allometric relation between D^2H and dry weight of culms of *Phyllostachys reticulata.*

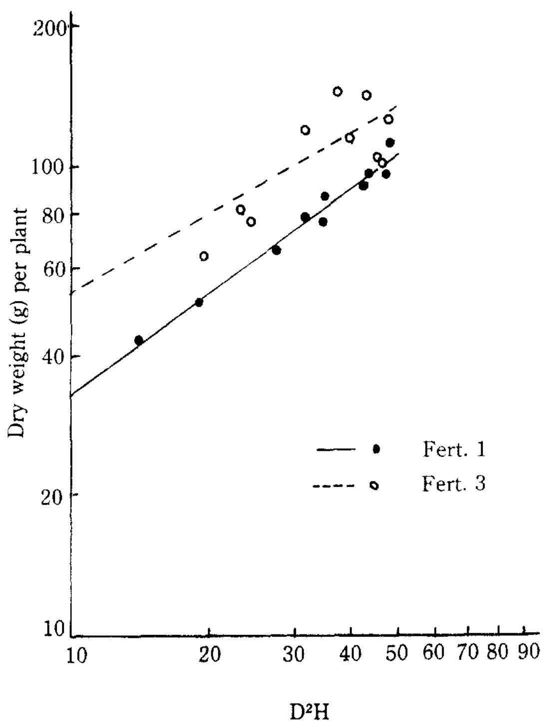

Fig. 8. Allometric relation between D^2H and dry weight of branches of *Phyllostachys reticulata.*

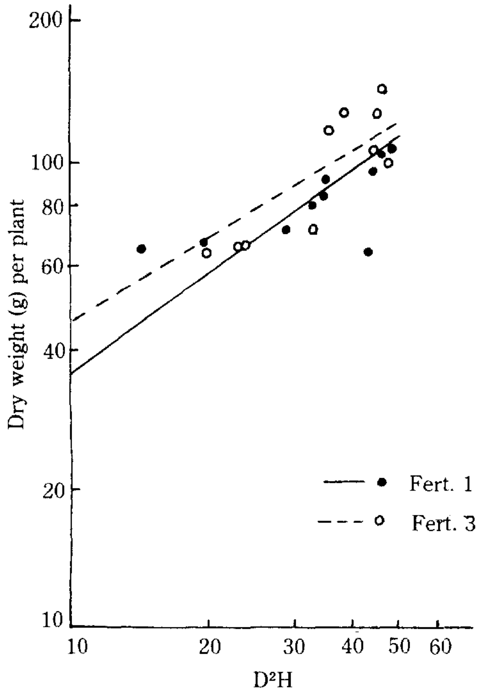

Fig. 9. Allometric relation between D^2H and dry weight of of leaves of *Phyllostachys reticulata*

D^2H - log Wl among D^2H devived from D.B.H. and H, culm weight (Ws), branch weight (Wb), and leaf weight (Wl).

I measured the biomass of yearling *Phyllostachys reticulata* by applying the allometry method on the experimental field which flowered 5 years before.

Table 12. Relation between D^2H (square of diameter at eye height x culm length) and dry weight of culm (Ws) of *Phyllostachys reticulata* under control and fertilized plot

Plot	$W = AX^h$
Cont.	$\log Ws = 0.7624 \log D^2H + \log 36.4754$
Fert. 1	$\log Ws = 0.4900 \log D^2H + \log 68.3912$
Fert. 2	$\log Ws = 0.7209 \log D^2H + \log 37.4369$
Fert. 3	$\log Ws = 0.6896 \log D^2H + \log 44.6992$
Fert. 4	$\log Ws = 0.6879 \log D^2H + \log 44.4529$
Fert. 5	$\log Ws = 0.7109 \log D^2H + \log 41.2477$
Fert. 6	$\log Ws = 0.6479 \log D^2H + \log 51.6059$
Fert. 7	$\log Ws = 0.7000 \log D^2H + \log 42.3741$

Table 13. Relation between D^2H (square of diameter at eye height x culm length and dry weight of branch (Wb) of *Phyllostachys reticulata* under control and fertilized plot.

Plot	$W = AX^h$
Cont.	$\log Wb = 0.7094 \log D^2H + \log 13.4431$
Fert. 1	$\log Wb = 0.7333 \log D^2H + \log 6.1532$
Fert. 2	$\log Wb = 0.6544 \log D^2H + \log 16.3705$
Fert. 3	$\log Wb = 0.5435 \log D^2H + \log 15.6314$
Fert. 4	$\log Wb = 0.2752 \log D^2H + \log 34.6258$
Fert. 5	$\log Wb = 2.1702 \log D^2H - \log 23.9828$
Fert. 6	$\log Wb = 0.9796 \log D^2H + \log 3.3297$
Fert. 7	$\log Wb = 1.3047 \log D^2H + \log 1.1468$

Table 14. Relation between D^2H (square of diameter at eye height x culm length) and dry weight of leaves (Wl) of *Phyllostachys reticulata under control and fertilized plot*

Plot	$W = AX^h$
Cont.	$\log Wl = 0.7096 \log D^2H + \log 12.8381$
Fert. 1	$\log Wl = 0.7015 \log D^2H + \log 7.1335$
Fert. 2	$\log Wl = 0.8664 \log D^2H + \log 4.1735$
Fert. 3	$\log Wl = 0.5924 \log D^2H + \log 11.6735$
Fert. 4	$\log Wl = 0.4255 \log D^2H + \log 19.2975$
Fert. 5	$\log Wl = 0.4737 \log D^2H + \log 14.6724$
Fert. 6	$\log Wl = 1.3418 \log D^2H - \log 1.2342$
Fert. 7	$\log Wl = 1.3393 \log D^2H - \log 1.3198$

Table 15. Biomass of the part above the ground of *Phyllostachys reticulata* grove estimated by the allometry method

(kg/10a)

Plot	Culm	Branches	Leaves	Total
Cont.	32.9496	52.4870	50.1544	135.5910
Fert. 1	690.3624	147.1644	152.3760	989.8548
Fert. 2	1029.1788	349.5777	199.4030	1578.1596
Fert. 3	766.7509	158.7355	141.2804	1066.7668
Fert. 4	844.7390	140.2214	137.2251	1122.1855
Fert. 5	904.2796	159.0534	139.1796	1202.5126
Fert. 6	916.5915	192.1489	169.3012	1278.0416
Fert. 7	564.9266	120.4591	89.5648	774.9505

Table 11, showed the diameter at eye height, the culm length and the dry weight of each organ of yearling *Phyllostachys reticullata* under each plots. Allometric relations derived on the basis of the data showed in Table 12, 13, 14.

Kim (1971) reported allometric relation, which was similar to a straight line, among D^2H, dry weight of culm Wb, and Wl of the Pinus rigida. The result of my experiment with *Phyllostachys reticulata* was different. The proportional relation could not be observed. This result indicates a characteristic of bamboo culm that the volume of the hollow part in the culm increases when the external volume of culm becomes larger. Watanabe *et al.* (1976) reported a similar result. The biomass per 10a obtained by the allometry method for each plot is shown in Table 15. The biomass of the part above the ground estimated

Table 16. Culm volume of *Phyllostachys reticulata* growing in each treatment plot

Plot	Culm volume per plant (cm^3)					
	Yearling measured in 1980			Yearling measured in 1981		
	Range	Mean S.E.	C.V.	Range	Mean S.E.	C.V.
Cont.	184.1-1527.8	549.0 ± 1.98	0.72	95.3-1446.7	662.0 ± 1.96	0.66
Fert. 1	34.8-970.1	387.0 ± 0.78	0.63	606.5-2061.0	1527.0 ± 1.46	0.30
Fert. 2	475.3-1360.4	788.0 ± 1.02	0.41	695.0-3000.9	1893.0 ± 2.28	0.38
Fert. 3	436.2-1374.7	722.0 ± 0.99	0.43	838.0-2065.5	1534.0 ± 1.34	0.27
Fert. 4	610.2-1830.0	1014.0 ± 1.08	0.34	1113.6-3771.7	1796.0 ± 2.38	0.42
Fert. 5	418.5-2244.4	868.0 ± 1.76	0.64	232.5-2648.6	1454.0 ± 2.23	0.48
Fert. 6	388.0-1403.0	821.0 ± 1.03	0.40	760.4-2744.0	1479.0 ± 1.89	0.40
Fert. 7	450.4-1490.9	775.0 ± 0.88	0.34	611.5-2096.2	1230.0 ± 2.01	0.49

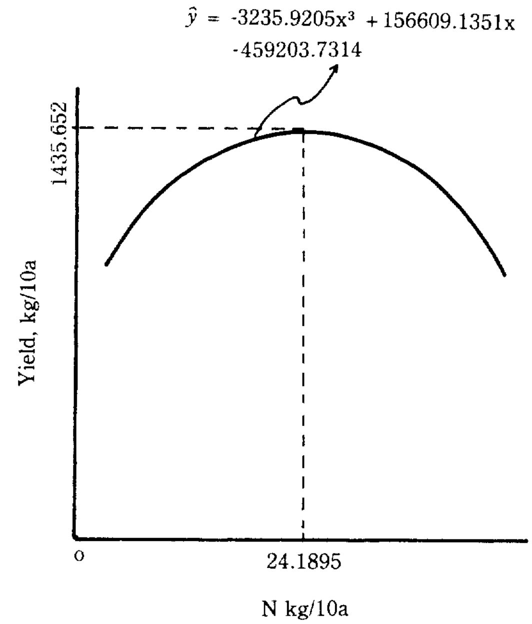

Fig. 10. The appropriate amount of N for rejuvenating *Phyllostachys reticulata*

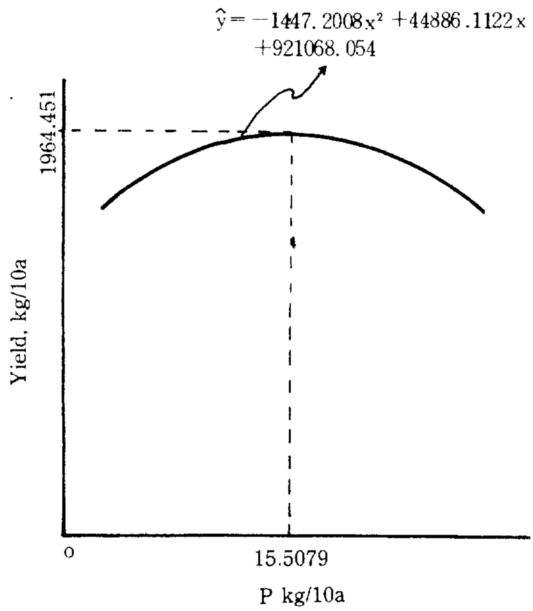

Fig. 11. The appropriate amount of P_2O_5 for rejuvenating *Phyllostachys reticulata.*

by the allometry method in the fertilized plots 2, 5 and 6 were 1578.1596, 1202.5126 and 1278.0416 Kg/10a, respectively. These are 4.6 times, 4.5 times and 4.7 times more than that of the non-fertilized

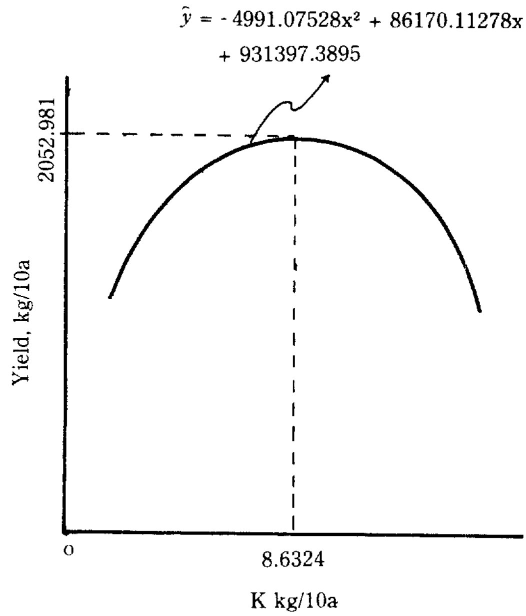

Fig. 12. The appropriate amount of K for rejuvenating *Phyllostachys reticulata.*

plot. Ueda (1961) had a similar result.

5. Appropriate fertilization of the three elements

The yield per 10a of the plots differentially fertilized is shown in Table 15, and the apporpriate amount of fertilization of the three elements is shown in Fig. 10, 11, 12. In the fertilized plot 2, the dry matter of the part above the ground is 1431.004 Kg/10a. This is a maximum result. Although, the culm volume and the boimass estimated by the allometry method were 3365m³/10a and 1578.1596 kg/10a, respectively. This is a high tendendency. Since it was not factorial experiment, the independent effect of each of N, P and K is not known. Nonetheless, the dry matter production of the plot 27.5 kg/10a of N-fertilizer to a bamboo grove 2 years after flowering. After two years of experiment, it was shown that the necessary amount of N, P and K for the maximum yield of dry matter according to the curve of the second order 24.19, 15.51, and 8.63 kg/10a, respectively. In a study of the fertilizer-management of a non-flowering bamboo grove, Ueda et al (1962) reported that the necessary amount of the N-fertilizer was 23 kg/10a. This is a little bit lower than the amount my experiment shows.

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