アカマツ同令単純林における材積, 重量, 熱量の成長に関する研究

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Study on the Growth of Volume, Weight and Calory in an Even-aged Pure Forest of AKAMATSU (*Pinus densiflora* Sieb. et Zucc.)

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Résumé

Study was made into the interrelation among the growths of volume, weight and calory in an even-aged pure forest of AKAMATSU (*Pinus densiflora* Sieb. et Zucc.), from the view point that the forests are classified into three categories by the purpose of production, namely the forest for production of timber for construction, the forest for production of timber for raw material, and the forest for production of fire-wood, and their theoretical and practical quantitative scale lies in volume, weight and calory, respectively.

The demand for wood has increased remarkably of late in Japan, and the structure of the demand has been undergoing a drastic change. In the pre-war period, the forest resources were utilized more for fire-wood than for timber, but after the war, in line with the rapid economic growth, the structure of demand for the forest products has changed year after year, and in general the demand for fire-wood has declined gradually and the demand for timber has increased sharply. Moreover, the past demand for timber used to be mainly for timber for construction such as civil, building and other constructions, but together with the development of the secondary industries with wood as raw material, the percentage of timber for raw material in the demand for timber has been increasing year after year. This tendency will be intensified more and more by the development of paper pulp, saccharification of wood, and other chemical industries aiming at a complete utilization of wood material, and consequently the concept of timber will be divided into two, timber for construction and timber for rawmaterial. Thus, the classification of the uses of forest trees in forestry has changed from two categories, timber and fire-wood, in the past to three categories, timber for construction, timber for raw material and fire-wood.

In the stage of production of forest trees, too, forests used to be classified into the timber forest and the fire-wood forest by the products aimed at. In order to cope with the above-mentioned change in the demand structure, however, it seems advisable to classify the forests into the forest for timber for construction, the forest for timber for raw material and the forest for fire-wood, according to the target of production. In this case, it would be rational in the appraisal of the productivity of the forest land if the quantitative measurement could be made in the scales of volume, weight and calory, according to the purpose of production. On the premises of the above-

mentioned division of stands by the purpose of production, the processes of growth in the quantitative units, namely volume, weight and calory, of forest trees were compared and the characteristics of the growths and the interrelation among them were clarified, through which the author aims at the establishment ot the bases for rational management of forests for production of timber for construction, timber for raw material and fire-wood.

An even-aged pure forest of AKAMATSU was selected for the study on the ground that AKAMATSU is one of the major tree species, is widely distributed, and occupies an important position as the forest resources in Japan. As AKAMATSU is the intolerant tree, it is easy to form an even-aged pure forest of AKAMATSU, and moreover, it is usable as timber for construction, timber for raw material and fire-wood, and it suits best the purpose of the present study aiming at the clarification of the growth relationship of forests of a single species and belonging to the forest management units for different purposes of production.

The present study deals with the weight and the calory of forest trees from the standpoint of forest mensuration, and it aims at the grasping of the weight and calory of individual trees and stands, including the internal variations, in the relationship with such factors as age, diametert breast height (D. B. H.), height, volume, annual ring density at breast height, which can be measured by ferest mensuration. Therefore, in the measurement of weight, the selected sample trees were cut at 0.2m, 1.2m, 3.2m…… above the ground according to the regular stem analysis, and a disk of 6 cm thickness was cut at each section. Each disk was sectionalized by each 5-year annual ring in four directions from the pith, namely the mountain side, the valley side and two perpendicular directions, and the progress of volume growth was the same time test pieces were cut from each growth period with continued age-grade. measured, and at The test pieces were shaved and oven-dried at 100°C in the constant-temperature hot air dryer, and their weight was measured. Then the volumes of the test pieces in the air-dry condition were measured by the volumenometer with mercury. The oven-dry specific gravity was computed from the above measurements. The weight of each age-grade was computed by multiplying the volume of the age-grade by the specific gravity of various parts of stem (average of four directions). The calculation was carried out from the stock to the top of the tree and the weight corresponding to the volume of each age-grade and the weight corresponding to the total stem volume were obtained. The total weight of the stem was divided by the volume inside bark and the tree mean specific gravity was obtained.

For the measurement of calory, the sample powder was made from the remainder of the disks after the sample pieces for the weight measurements were cut out. In this case, as the 5-year age-grade did not produce enough sample powder for the measurement, 10-year was selected as one age-grade, and the samples for the four directions were combind into one sample, and the sample powder passing through the

60-mesh sieve was used in the measurement. The sample powder was molded and oven-dried in the constant-temperature drier and weighed. And the calory corresponding to the oven-dry weight was measured. The Combustion Laboratory Type Adiabatic Calorimeter specified by JISM 8802 was used in the measurement. More than two measurements were made with each sample, and the values deviating not more than 0.5% or 50 cal/g from the mean value were averaged to obtain the calorific value. Since this calory corresponds to the oven-dry weight of the unit volume, the tree total calory computed as in the case of weight, divided by the volume inside bark was termed the tree mean calory. In general, the calory is expressed per unit weight, and this gravimetric calory was differentiated from the volumetric calory expressed per unit volume.

It is impossible to carry out the above-mentioned measurements directly with all the trees constituting the stand, and there is no other way than to select some sample trees representing the average conditions of the stand and estimate the total stand conditions from the measurements with them. Now it is necessary to find how to select the sample trees which would give the average values of the oven-dry weight, combustion calory, etc. Thus, for the purpose of determining the method of rationally selecting the sample trees by which to estimate the oven dry weight and the combustion calory of the whole stand, the author classified the trees constituting an even-aged pure forest by diameter class, felled sample trees from each diameter class, and measured the volume, weight and calory, and estimated the stand volum, stand weight and stand calory, and established the relationship between the average weight tree and average calory tree and the average volume tree. And thus the author established the rational method of selection of sample trees for the estimation of the weight and calory of a stand. Based on the above, the author next prepared the stand volume yield table, the stand weight yield table and the stand calory yield table with many stands of different ages, by the measurements with the sample trees selected for the estimation of the weight and calory. And by these yield tables, the author studied the differences among the chronological changes of the volume, weight and calory of the stand and their growths.

The results and considerations of the study are summarized in the following.

1. Volume, Weight and Calory of Trees by Diameter Class in an Even-aged Forest

The AKAMATSU forest in Yasakayama National Forest located at Asakura-machi, Asakura-gun, Fukuoka Prefecture was selected as the test stand. It has 0.24 ha of area, a total of 320 trees and 65.1044 m^3 of volume, is aged 44 years, has 6–34 cm of D. B. H. or 16.8 cm of mean D. B. H., 7–22 m of height or 15.5 m of mean height, 1,333 trees per ha, and 271.3 m^3 of volume per ha. The stand composition is shown in Fig. 1 expressed in terms of the distribution of number of trees by diameter class divided by each 4 cm, and is a unifom even-aged pure forest.

It was decided to take 3 sample trees from each diameter class, and the trees with the mean height in each diameter class were selected as sample trees. As there were some diameter classes which had not enough number of trees, the number of sample trees selected was 22 in all. The results of measurements of weight and calory with these sample trees are given in Table 2 and Table 4.

1) Mean Specific Gravity

The mean specific gravity of the sample trees selected by diameter class from an even-aged stand is observed to have the following relations with other factors.

(1) The relation with D. B. H. is expressed by

$$y=0.410+0.0112x-0.000282x^2$$

From this equation, it is seen that the mean specific gravity of trees constituting an even-aged forest increases with the increase of D. B. H. to a certain diameter (19.9 cm for the present test stand) and it decreases beyond the limit, and the relation is expressed by a quadratic regression equation. And excepting small suppressed trees, there is a tendency that the mean specific gravity decreases with the increase of the diameter class. (See Fig. 2) This agrees fairly well with a series of Hirai's reports(7,8,9,10,11,12) and with Hartig's report on Fichte.

In consideration of the above results, in case the stand volume of an even-aged forest is the same, it would be possible to increase the substantial weight per unit volume of the stand by managing the forest so as to form a stand composition of small dispersion of D. B. H., with emphasis on the stand growth rather than on the growth of individual trees, by effecting a high stand density.

(2) The mean specific gravity has a high correlation with the average specific gravity at breast height and their relation is expressed by

$$y=0.163+0.6259x$$

The mean specific gravity is expressed by a linear regression equation of the average specific gravity at breast height, and the correlation is very high as seen from 0.90 of the cofficient of correlation. (See Fig. 5.) Consequently, as in the case of the report on RYUKYUMATSU(56), it is possible to estimate the mean specific gravity of individual trees from the average specific gravity at breast height.

2) Tree Weight

With the trees by diameter class forming an even-aged forest, the oven-dry weight of stem has the following relation with other factors.

(1) The oven-dry weight of stem has the following relation with D. B. H.

$$\log y=-1.0118+2.3208\ \log x$$

Namely, the relation between the tree weight and D. B. H. expressed in logarithm is expressed by a linear regression equation, and the weight increases with the increase of D. B. H.. (See Fig. 6.) This differs from the tendency of the mean specific gravity, and the tree weight is influenced strongly by the increase of volume or its transverse expression, D. B. H..

(2) The relation with the volume is expressed by

$$\log y = -1.3089 + 1.01597 \log (10{,}000x)$$

The tree weight has a very high correlation with the volume, and it increases proportionally with the increase of volume. (See Fig. 8.) This agrees with the reports on RYUKYUMATSU[56] and Ponderosa Pine[5].

3) Mean Gravimetric Calory

The mean gravimetric calory of trees by diameter class in an even-aged AKAMATSU stand is constant irrespective of changes of other factors, and averages 4,800 cal/g. (See Fig. 11.) This measurement agrees fairly well with Miura's measurement[28], and therefore, the gravimetric calory of AKAMATSU is considered to be 4,800 cal/g.

4) Mean Volumetric Calory

The mean volumetric calory of trees by diameter class, different from the mean gravimetric calory, has the following relation with other factors.

(1) The mean volumetric calory has the following relation with D. B. H.

$$y = 2046 + 46.85x - 1.1849x^2$$

Namely, the mean volumetric calory increases with the increase of D. B. H. until it reaches a maximum at a certain diameter (19.8 cm for the present test stand) and decreases beyond this limit, and the relation is expressed by a quadratic regression equation. (See Fig. 12.) This tendency is the same as in the case of the mean specific gravity, but the decline of the volumetric calory with the increase in diameter class is not as sharp as in the case of the mean specific gravity. The semblance of the regression equations will be well understood by the fact that the relation between the mean volumetric calory and the mean specific gravity is expressed by a linear regression equation as stated in a later section.

(2) The relation with the average specific gravity at breast height is expressed by

$$y = 711 + 3135.7x$$

The mean volumetric calory increases proportionally with the increase of the average specific gravity at breast height and their correlation is very high. (See Fig. 15.) Consequently, with AKAMATSU, as in the case of the mean specific gravity, it is possible to estimate the mean volumetric calory from the measurement of the average specific gravity at breast height.

(3) The relation with the mean specific gravity is expressed by

$$y = 37 + 4724.7x$$

The mean volumetric calory increases linearly with the mean specific gravity. (See Fig. 16.) Thus, an increase of substantial weight per unit volume of trees means an increase of calory of the trees, and consequently, if the mean specific gravity of trees constituting the stand could be increased by the management to increase the stand density, it would at the same same time increase the mean volumetric calory of the trees.

5) Tree Calory

The following relations exist with respect to the calory of the trees by diameter class in an even-aged stand.

(1) The relation with D. B. H. is expressed by

$$\log y = -0.3342 + 2.32838 \log x$$

The tree calory and D. B. H. expressed in logarithm have a relation expressed by a linear regression equation as in the case of the tree weight, and the tree calory increases sharply with the increase of D. B. H.. (See Fig. 17.) It is only natural from the fact that the relation between the mean volumetric calory and the mean specific gravity is expressed by a linear regression equation, that the regression equation is similar to that in the case of weight.

(2) The relation with the volume is expressed by

$$\log y = 2.2983 + 1.0184 \log (10{,}000x)$$

The correlation between the tree calory and the volume expressed in logarithm is very high, and they are linearly related. (See Fig. 19.)

6) Relation between Average Volume Tree and Average Weight Tree and Average Calory Tree of a Stand

The relationship between the average volume tree and the average weight tree and the average calory tree in the present test stand was studied with a view to establishing the method of selecting the sample trees for the estimation of the oven-dry weight and the combustion calory of stand in an even-aged pure forest.

The average volume tree of the test stand was computed, from the data of the every tree measurement, to be a tree of 17.9 cm of D. B. H. and 15.5 m of height.

With respect to the the average weight tree, the weight of tree corresponding to the D. B. H. was cnmputed by the regression equation (5) between the D. B. H. and the tree weight. And the stand weight was obtained by multiplying these values of weight by the numbers of trees in the diameter classes, and then the stand weight is divided by the total number of trees to get the average weight per tree in the stand. Then the D. B. H. of the average weight tree was computed inversely by the equation (5) to be 17.8 cm.

With respect to the average calory tree, the average calory per tree was computed by the regression equation (15) between the D. B. H. and the tree calory, in a similar manner to that for the weight, and the D.B.H. of the stand average calory tree was computed to be 17.8 cm.

Thus the D.B.H.'s of the average volume tree, the average weight tree and the average calory tree of the stand were 17.9 cm, 17.8 cm and 17.8 cm respectively, differing by only 0.1 cm. As this much of difference is considered to be an error in measurement, it may well be considered that the D.B.H.'s of the average volume tree, the average weight tree and the average calory tree agree one another.

It is clear that the average volume tree and the average cross-sectional area at breast height tree agree in case the form-height (hf) of the whole forest trees are considered to be same, namely in case of a uniform forest condition with little deviation of size among the trees in the stand. The D. B. H. of the average cross-sectional area at breast height tree in the present stand is computed to be 17.6cm, differing by only 0.3cm from that of the average volume tree.

From the above results, in an even-aged pure stand with uniform forest condition, the average cross-sectional area tree, the average volume tree, the average weight tree and the average calory tree can be considered to have the same D. B. H..

Next the averages of the mean specific gravity and the mean volumetric calory of the stand are computed. From the regression equation (1) between the D.B.H. and the mean specific gravity, the mean specific gravity corresponding to D.B.H.'s is computed, and the mean specific gravity is multiplied by the numbers of trees in the diameter classes to get the weight of each diameter class. The weight is then divided by the total number of trees of the stand and the average specific gravity of the stand is obtained. Then the D. B. H. giving the average of mean specific gravity of the stand is computed inversely by the equation (1) to be 13.9 cm and 25.9 cm.

The D.B.H. giving the average of the mean volumetric calory of the stand is obtained by the regression equation (10) between the D.B.H. and the mean volumetric calory, in a similar manner to the case of the average of mean specific gravity, to be 13.7 cm and 25.8 cm.

Thus, in an even-aged pure forest, the averages of the mean specific graivty and the mean volumetric calory of the stand occur at two different diameter classes, because of the quadratic relationship between the mean specific gravity and the mean volumetric calory of trees and the D.B.H.. Generally, an even-aged pure forest is composed of the main tree-crop and the dominated trees which show different progress of growth. Therefore, it seems rational to regard the two different diameters as the average diameter of the main tree-crop and that of the dominated trees and to obtain the average mean specific gravity and the average mean volumetric calory by selecting the average trees for the main tree-crop and the dominated trees separately.

Based on this ground, it is pertinent in selecting sample trees of many even-aged stands of different ages, to choose as the sample trees the trees with the D.B.H. corresponding to the average volume trees of the main tree-crop and of the dominated trees separately. And with uniform forests, the average volume tree and the average cross-sectional area tree are the same. Consequently, in selecting average volume tree, average weight tree and average calory tree of a stand as sample trees, it serves to the purpose to select average cross-sectional area tree with the main tree-crop and the dominated trees separately.

2. Volume, Weight and Calory of Trees in Even-aged Stands of Different Ages

The method of selecting the sample trees for the measurement of volume, weight and calory in an even-aged stand having been clarified, the relationship among the growths in volume, weight and calory of trees of a variety of even-eged stands of different ages were studied by selecting the average tree with the main tree-crop and the dominated trees separately.

The test area was selected in Ashikita District in Kumamoto Prefecture. The sketch map, the geological map and the climatic conditions are shown in Fig. 22, Fig. 23 and Table 6.

The results of measurements of weight and calory with the sample trees selected for the main tree-crop and the dominated trees separately from each stand are given in Table 14 and Table 24.

1) Mean Specific Cravity

The relationship between the mean specific gravity and various factors of trees classified by age are studied in the following.

(1) The relation with the age of the main tree-crop is expressed by

$$y=0.357+0.0082x-0.000085x^2$$

The mean specific gravity is expressed by a quadratic regression equation, and increases with age to a certain age (48 years for the present stands), beyond which limit it decreases with age. (See Fig. 45.) This differs from the case of RYUKYUMATSU[56] with which the mean specific gravity increases with the advancenent in age, and it may be due either to the difference in the characteristics of the trees and the growth environments or to the fact that the data for old trees are lacking. No consistent tendency with age is observed with the mean specific gravity of the dominated trees. The mean specific gravity of the dominated trees after the stand has been formed is considered to be constant and averages 0.529.

(2) The relation with the average specific gravity at breast height is expressed by

$$y=0.111+0.7446x$$

The mean specific gravity is expressed by a linear regression equation both with the main tree-crop and with the dominated trees, and the correlation is very high, the coefficient of correlation being 0.972. (See Fig. 49.)

This relation is observed in the relation between the mean soecific gravity at breast height of individual trees in an even-aged stand, too, and was reported with RYUKYUMATSU[56], KARAMATSU[24], Shortleaf Pine and Loblolly Pine[1,2]. Therefore, it is possible to estimate the mean specific gravity of trees from the measurement of the average specific gravity at breast height.

2) Tree Weight

The oven-dry weight of the stem of trees classifed by age has the following relationship.

(1) The relations of age with the weight of the main tree-crop and that of the dominated trees are expressed by

Main tree-crop $\log y = -1.8825 + 2.67324 \log x$

Dominated tree $\log y = -2.5862 + 2.88275 \log x$

The tree weight increases sharply with age. (See Fig. 50.) In consideration of the fact that the mean specific gravity of the main tree-crop is expressed by a quadratic regression equation of age as stated before, the weight of the main tree-crop should be influenced by not only volume but also the mean specific gravity. In this case, however, as the rate of increase of the volume with age is greater than the rate of change of the mean specific gravity, the influence of the mean specific gravity on the weight is canceled by the influence of the volume, and the relation is expressed statistically by a linear logarithmic equation. On the other hand, in the case of the dominated trees, the weight depends only on the volume, because there is no particular tendency in the mean specific gravity. With these regression equation, the examination of difference was made by the covariance analysis, and as shown in Table 15, no difference was observed in the coefficient of regressions, and the difference was observed only in the adjusted mean value. Namely, there is no difference in the change of weight with age, but the difference is observed in the mean value, and the weight of individual trees of the same age differs according to the quality of individual trees.

(2) The relation between the volume and the weight of trees is expressed by

Main tree-crop $\log y = -1.4731 + 1.0549 \log (10{,}000x)$

Dominated tree $\log y = -1.2911 + 1.0063 \log (10{,}000x)$

Both the main tree-crop and the dominated trees have a very high correlation with the volume, and the weight increases with the increase of volume. (See Fig. 53.) Examination of difference by the covariance analysis with these regression equations gives the results as shown in Table 18, and significant differences are observed both in fhe coefficent of regression and the adjusted mean value. Consequently, it is judged that the regression equation of the weight of individual trees with the volume for the main tree-crop differ from that for the dominated trees.

Since the mean specific gravity of the main tree-crop is expressed by a quadratic regression equation of age and no particular tendency is observed in the mean specific gravity of the dominated trees, the weight of the main tree-crop is influenced by the mean specific gravity and that of the dominated trees is not influenced by the mean specific gravity but depends solely on the volume. Consequently, the coefficient of regression for the dominated trees is close to 1 and that for the main tree-crop may be somewhat larger. It is considered to be the influence of the mean specific gravity that the coefficient of regression for the main tree-crop is larger than that for the dominated trees, and it has managerial significance from the standpoint of production of timber for raw material utilizing the substantial weight of the trees.

3) Mean Gravimetric Calory

The mean gravimetric calory of the trees taken from the main tree-crop and the dominated trees in even-aged stands of different ages, is nearly constant irrespective of the age and other factors, and the average value is 4,782 cal/g. This agrees well with the afore-mentioned measurement with trees by diameter class and the measurement by Miura[28]. Thus, the gravimetric calory of AKAMATSU is estimated to be about 4,800 cal/g, and is relatively high as compared with other species.[44. 45]. (See Fig. 59.)

4) Mean Volumetric Calory

While the mean gravinetric calory of trees is constant irrespective of age, the volumetric calory has the following relations.

(1) The mean volumetric calory of the main tree-crop has the following relation with age.

$$y=1738+41.707x-0.474657x^2$$

The mean volumetric calory is expressed by a quadratic regression equation, and increases with age to a certain age (44 years in the present study), beyond which it decreases with age. (See Fig. 60.)

The mean volumetric calory of the dominated trees has no definite relation with age, and is nearly constant, averaging 2,568 cal/cm^3.

(2) The relation with the average specific gravity at breast height is expressed by

$$y=-2166+14210x-13056x^2$$

The average specific gravity at breast height has a high correlation with the mean specific gravity and also with the mean volumetric calory. (See Fig. 64.) Therefore, with AKAMATSU trees, not only the mean specific gravity but also the mean volumetric calory can be estimated from the measurement of the average specific gravity at breast height.

(3) The relation with the mean specific gravity is expressd by

$$y=73+4651x$$

The calory per unit volume increases with the increase of the mean specific gravity of trees. (See Fig. 65.) This relationship was observed with the trees classified by diameter class. Consequently, if the mean specific gravity of trees can be increased by the working method, an increase of weight leads to an increase of calory.

4) Tree Calory

The tree calory of trees has the following relations with various factors.

(1) The relation with age is expressed by

Main tree-crop $\log y = -1.4572 + 2.81250 \log x$

Dominated tree $\log y = -2.0659 + 2.98169 \log x$

The calory and age of trees expressed in logarithm are related by linear regression equations, and the calory increases sharply with the increase of age. (See Fig. 66.) This relation is the same as in the case of the relation of weight and age. As stated before, the mean volumetric calory of the mein tree-crop is expressed by a quadratic regression equation of age. Since the increase of volume with age is so great that the influence of the change of the mean volumetric calory is canceled, and statistically the tree calory is expressed by the linear logarithmic regression equations. The examination of difference by the covariance analysis with these regression equations gives the results shown in Table 26. No difference is observed in the coefficient of regression, and the difference is observed with the adjusted mean value only. Namely, there is no difference in the change of calory with age, but difference is observed in the mean value, and the tree calory differs according to the quality of individual trees even of the same age.

(2) The relation with the stem volume is expressed by

Main tree-crop $\log y = 5.3776 + 1.0434 \log (10{,}000x)$

Dominated tree $\log y = 5.4101 + 0.9958 \log (10{,}000x)$

The calory and the volume exprssed in logarithm have a very high correlation, and the calory increases with the increase of the volume. (See Fig. 69.) In view of the fact that the mean volumetric calory of trees is expressed by a quadratic regression equation of age, it cannot be said that the tree calory is perfectly proportional to the volume. Namely, the influence of the mean volumetric calory on the tree calory is considered to be similar to the influence of the mean specific gravity on the tree weight.

As seen in Table 29 giving the results of the examination of difference by the covariance analysis with these regression equations, no difference is observed in the adjusted mean value, and the difference is observed in the coefficient of regression. Namely, the regressien equation of the tree calory with the volume for the main tree-crop differs from that for the dominated trees, and the rate of increase of tree calory according to the volume differs.

3. Volume, Weight and Calory of Stand

The volume, weight and calory of stands were studied by preparing the yield tables.

1) Preparation of Yield Tables of Volume, Weight and Galory

(1) Volume Yield Table

The volume yield table was prepared with the data of 37 sample stands by the Stand Volume Yield Table Preparation Rule of the National Forest. The summarized table is given in Table 11.

(2) Weight Yield Table

The foregoing yield table of volume is for the volume including the bark. For the stand weight yield table corresponding to the volume table, the volume was divided into the volume inside bark and the volume of bark by the bark percentage, and the mean specific gravity was applied to the former and the specific gravity of bark to the latter. Table 23 is the summarized weight yield table.

(3) Calory Yield Table

The calory yield table was prepared by applying the mean volumetric calory to the volume inside bark and the volumetric calory of bark to the bark. Table 34 is the summarized calory yield table.

2) Volume, Weight and Calory of Main Tree-crop

From these yield tables, the volume, weight and calory of the main tree-crop and their growths are tabulated in Table 42. It is noted in the table that the average volume growth of the AKAMATSU stands in Ashikita District reaches its maximum in 25 years, and the weight and calory reach their maximums in 30 years, namely the weight and calory falls 5 years behind the volume in reaching their maximums. The same tendeney is observed with the reletion of volume and weight of RYUKYUMATSU[56]. As the grounds for the average growths of weight or calory of the stand falling behind that of volume are considered the influence of the chenges of the mean specific gravity or the mean volumetric calory and the decrease of number of trees of the stand accompanying the chronological change of age. Since the mean specific gravity and the mean volumetric calory of trees are expressed by quadratic regression equations of age and reach their maximums at certain ages, they continue to increase after the volume growth of the stand has reached its maximum. Consequently, the average growth of weight or calory of trees reaches its maximum somewhat later than the average growth of volume. With reference to the main tree-crop in the yield table, the tendency of decrease of number of trees in the stand with age adds to the delay of the average growth of weight or calory reaching its maximum, and the former falls considerably behind the latter. On the other hand, the specific gravity and the volumetric calory of the main tree-crop obtained by dividing the chronological weight and calory of the yield tables by the volume reach their maximums in 45 years. From these relations, too, it is understood that the total growth curves of weight and calory have steeper and continued rate of increase as compared with the total volume growth curve, and their average growths reach the maximums later than the volume growth.

The reason why the growth curves of weight and calory nearly agree with each other is because the mean specific gravity and the mean volumetric calory are in a proportional relationship.

3) Stand Volume, Weight and Calory

The stand volume, weight and calory and their growths are given in Table 43.

The average growth of stand volume reaches its maximum in 25 years, and those of stand weight and calory in 30 years, or 5 years later than the former. This agrees with the case of the main tree-crop, and it is considered to be because the mean specific gravity and the mean volumetric calory of the main tree-crop fall behind the volume in reaching their maximums, while the mean specific gravity and the mean volumetric calory of the dominated trees have no particular chronological change but remain practically constant, and consequently the stand weight and calory are influenced dy those of main tree-crop.

4) Total Yields of volume, weight and Calory

The total yields and the annual average yields of volume, weight and calory are shown in Table 44.

The annual average of the total volume yields reaches its maximum in 35 years and those of weight and calory in 40 years, or 5 years later than the former. The reason why the average yields of weight and calory fall behind that of volume is the same as in the case of the stand volume, weight and calory. However, the ages at which they reaeh their maximums are 10 years higher than in the case of the stand volume, weight and calory. This phenomenon is explained by the fact that the total yield represents the sum total of the main tree-crop and the dominated trees, and similar phenomena are observed in the general stand yield tables.

To summarize the foregoing studies into the relationship among the growths of volume, weight and calory of AKAMATSU stands, the maximum periods of weight and calory occur about 5 years later than that of volune in all cases, and the maximum periods of weight and calory agree with each other fairly well. Therefore, when the cutting age for AKAMATSU forets is considered in terms of the maximum yields, the cutting age for the stands aiming at timber for raw material or fire-wood may be somewhat higher than that for the stands aiming at timber for construction. However, no difference is seen between the cutting ages for stands for timber for raw material and for the stands for fire-wood.

4. General Consideration

The interrelation among the growths of volume, weight and calory of even-aged pure forests of AKAMATSU having been clarified, general consideration is now made on the present study.

(1) so far, the volume has deen generally used as the scale for the quantitative measurement of trees. However, even in case the tree volumes are the same, the substantial weight or calory per unit volume differ considerably by species. Therefore, in forests for production of timder for raw material and fire-wood, increases of weight growth or calory growth can be expected by selecting proper species and quality of trees, with the substantial weight or calory per unit volume

taken into consideration.

(2) Excluding the suppressed small-diameter trees, generally the larger the volume growth of trees, the smaller the substantial weight or calory per unit volume. Consequently, in case an AKAMATSU forest is meant for timber for raw material, it is possible to increase the production in weight of the stand by increasing the substantial weight per unit volume of trees forming the stand, by putting stress on higher stand density and the stand growth rather than on the growth in size of individual trees and working so as to form stands with smaller dispersion of D.B.H.. The same applies to the case where an AKAMATSU stand is intended for fire-wood. Thus the characteristics of working technipue for the forests for timber for raw material and that for fire-wood have much in common, but they are different from the working technique for the forest for timber for construction.

(3) It was made clear that the average volume tree, the average weight tree and the average calory tree of an even-aged stand agree with one another in the diameter at breast height. Consequently, if sample trees representing the average conditions of volume, weight or calory of an even-aged pure forest are to be selected, the object would be attained by selecting trees with the average cross-sectional area. However, it would be more rational to take trees with the average cross-sectional area from the main tree-crop and the dominated trees separately, in view of the average mean specific gravity and the average mean volumetric calory of the stand.

(4) The average specific gravity at breast height of AKAMATSU trees has a very high correlation with the mean specific gravity and the mean volumetric calory, and it is expressed by a linear regression equation. Therefore, as a simplified method of obtaining the specific gravity or the volumetric calory of trees or stands, it is practicable to estimate the mean specific gravity or the mean volumetric calory indirectly by the use of the regression equations from the measurement of the average specific gravity at breast height.

(5) The mean specific gravity and the mean volumetric calory of the main tree-crop of AKAMATSU differ by age and by diameter class. But the weight and calory of trees are practically proportional to the volume, in spite of the changes in the mean specific gravity and the mean volumetric calory, because their influences are smaller than that of changes of volume. On the other hand, the mean specific gravity and the mean volumetric calory of the dominated trees do not change by age, and are larger than those of the main tree-crop until they reach the prime age. Therefore, in the use of trees, it would be rational to use the main tree-crop as timber for construction and the dominated trees as timber for raw material and fire-wood.

(6) The mean specific gravity and the mean volumetric calory of AKAMATSU trees are proportional to each other both by age and by diameter class. Therefore,

to try to increase the weight of trees by working method means the increase of calory of the trees.

(7) When the purpose of production for the even-aged forest of AKAMATSU is set for timber for construction, timber for raw material or fire-wood, if the purpose of the respective production is to achieve the maximum volume, weight or calory, it would be necessary to set the cutting age for the forest for timber for raw material and fire-wood higher than that for the forest for timber for construction, because the chronological changes of the mean specific gravity and the mean volumetric calory fall behind that of the volume. However, the average yields for the forest for timber for raw material and the forest for fire-wood reach their maximums at practically the same age.

(8) The author has clarified in the present study the interrelation among the growths of volume, weight and calory of an even-aged forest of AKAMATSU and gave some considerations. If similar relationship is clarified with other species, the management policy for the respective production forests would be more scientifically established, by studying the working technique separately to suit the purposes of production for timber for construction, timber for raw material and timber for fire-wood.