AN ABSTRACT OF THE THESIS OF

Henry Raymond Fortmann for the M.S. in Farm Crops
(Name) (Degree) (Major)

Date Thesis presented May 1, 1942

Title A Study of the Interrelationships and Effects of Certain Factors and Cultural Treatments Affecting the Quality of Hops

Abstract Approved: [redacted]
(Major Professor)

Results and data from two year's experimentation with factors affecting hop quality are analyzed. Quality of a sample of hops is defined as the degree to which the sample will fulfill the functions for which it is used in the production of beer. Various physical factors used to indicate quality are defined and the methods used in making the measurements are described. A resume' of the methods of statistical analysis and definitions of the statistics are included.

Analysis of variance reveals significant differences between variety means and between irrigation treatment means. There is a significant interaction between varieties and irrigation treatments. There are no significant differences between fertilizer treatment means.

The average analysis of seed content for the Fuggles variety is significantly higher than that for Late Clusters. The average analysis in the Late Cluster variety is significantly higher than Fuggles for aroma, amount of lupulin, color and condition of lupulin, general appearance, percentage broken cones, total soft resin, alpha resin, beta resin, and preservative value.

The average color analysis of samples from irrigated plots is significantly higher than that from non-irrigated plots. The amount of lupulin, and the color and condition of lupulin are significantly higher than the non-irrigated sample averages.

Significant interaction between varieties and irrigation treatments occurs with the amount of lupulin and the

percentage of beta resin. With the amount of lupulin, there is a negative reaction of the Fuggles variety to irrigation. The Late Clusters variety shows a significant negative reaction to irrigation with beta resin.

Valuable reference tables have been compiled. Statistics which have been calculated and compiled include (1) averages of all factors for the major production areas in 1940 and in 1941, (2) averages of all factors for lots of hops under various cultural treatments in 1941, (3) correlation coefficients between factors in various lots of hops in 1940 and in 1941, (4) regression coefficients between physical and chemical factors for different lots of hops in 1940 and in 1941, (5) multiple correlation coefficients between the several factors and each of the chemical factors for the different lots of hops in 1940 and in 1941, (6) standard error of estimate for the various chemical factors for all lots, and (7) the F values indicating the significance of each of the physical factors in accounting for variations of the chemical factor.

The correlation coefficients obtained indicate that certain highly significant and constant relationships exist between physical characters and between physical and chemical characters.

The regression coefficients and F values obtained show that some of the physical factors studied are susceptible of accurate measurement and will be of definite value in estimating the resin content of hops. Seed content, leaf and stem content, aroma, amount of lupulin, and color (hue) appear to be the factors which are most influential and condition of lupulin, and general appearance were not closely correlated to resin content. The data indicated that broken cones do not have any effect on the amount of resin.

The suggestion is made that work is necessary to determine the effect of the various factors on beer itself.

The results which are obtained are based on samples covering a wide range of quality. Indications are given that the methods of physical analysis have improved considerably during the two years of the investigation and confidence may now be placed on their reliability.

A STUDY OF THE INTERRELATIONSHIPS AND EFFECTS OF CERTAIN FACTORS AND CULTURAL TREATMENTS AFFECTING THE QUALITY OF HOPS

by

HENRY RAYMOND FORTMANN

A THESIS

submitted to the

OREGON STATE COLLEGE

in partial fulfillment of
the requirements for the
degree of

MASTER OF SCIENCE

May 1942

APPROVED:

[redacted]

Professor of Farm Crops

In Charge of Major

[redacted]

Head of Department of Farm Crops

[redacted]

Chairman of School Graduate Committee

[redacted]

Chairman of State College Graduate Council

ACKNOWLEDGMENT

The writer wishes to express his sincere appreciation for the assistance of the collaborators in the hop research program of the Oregon Agricultural Experiment Station and for the financial support of the project by the Agricultural Research Foundation from the Brewer's Hop Research Grant.

Special acknowledgment is due to Dr. D. D. Hill, Professor of Farm Crops, for the guidance and stimulation he has provided and for his generaous cooperation in providing assistants and materials.

Grateful acknowledgment is made of the services rendered by Dr. R. E. Fore in supplying samples; Mr. D. E. Bullis for supervising the chemical analysis; Mr. R. Van Pelt, Mr. J. G. Ruggles and Mr. G. Alderton in running chemical analysis on the samples; and Mr. J. Sather in collecting and compiling data.

Counsel rendered by Professor G. R. Hyslop, In Charge, of the Division of Plant Industries, has been greatly appreciated.

TABLE OF CONTENTS

INDEX OF TABLES

A STUDY OF THE INTERRELATIONSHIPS AND EFFECTS OF CERTAIN FACTORS AND CULTURAL TREATMENTS AFFECTING THE QUALITY OF HOPS

INTRODUCTION

The use of hops (Humulus lupulus, L.) is a comparatively recent innovation in brewing technique. Previous to its introduction, other bittering plants such as wormwood, horehound, gentian, and ground ivy were employed. The term lupulus is derived from the Latin, lupus salictarius, or wolf of the willow which become entwined and choked to death just as sheep from the flock are caught and killed by wolves.

The use of hops in beer was the result of empirical experience. From the first it was noted that they convey to beer a fine bitterness and delightful aromatic flavor.

A review of the literature on hops reveals the fact the hop growers, hop dealers and brewers have long been cognizant of the need for standard methods of analyzing hop quality. More recently, there has been an increasing interest on the part of both producers and consumers of hops for the establishment of a uniform set of hop grades and standards. This interest led to the formation of the Brewer's Hop Research Institute. The ultimate goal of the investigations in progress is to establish a set of grades and standards for hops.

A set of grades and standards must primarily be a reflection of the quality and condition of the commodity in question. This immediately raises the question; "What constitutes quality in hops?" The opinions and answers to this query are many and diverse. Perhaps the best criterion of quality of a sample of hops is the degree to which the sample will fulfill the functions for which it is used in the production of beer. Today, the functions of hops in beer are recognized to include: (1) contributing a desirable bitter quality to the flavor, (2) contributing a preservative action against microorganisms, (3) acting as a clarifying precipitation agent, (4) influencing head retention, and (5) adding aromatic qualities. Of principal importance in brewing are the bitter resins, which influence flavor, foam, and preservative value; the tannins and perhaps the pectins, which affect the colloidal stability; and finally, the volatile hop oils, which affect fragrance and aromatic qualities.

Thus, a set of grades should take into consideration the resin content of the sample; any factors which will affect the aroma that will be transmitted to the beer; extraneous material, such as seeds, stems and leaves, mold or diseased cones, as it may have an effect on flavor; extraneous material in that it is useless material which should be considered in much the same sense as dockage; and finally, any factors which will influence the brew in any other way.

The objectives of this paper are threefold: The first of these is to measure the effect of irrigation, fertilizer treatments, and varieties on the physical and chemical factors measured. The second objective is to establish the relationship which exists between the various factors considered. This will be accomplished by determining the correlation coefficients between the various physical factors and between the physical and chemical factors. The third objective will be to measure the absolute relationship between the physical factors measured and the chemical variables for each of several lots of hops from different sources. This will be accomplished by determining the regression coefficients.

From the information which will be obtained from the above listed studies, it will be possible to determine which physical factors can be used to advantage in estimating the resin content and preservative value of hops. It will be possible to set up an equation with which the chemical factors can be estimated by using physical measurements. To summarize, the investigations will provide a basis for the formulation of a preliminary set of grades.

REVIEW OF LITERATURE

Investigations in 1938 at the Oregon State College Experiment Station (2) showed no relationship between the amount of soft resins and the physical character of hops.

Breuer (3) states that the different varieties of hops can be classified into three groups on the basis of the size of strobiles or strigs. Hops with large strobiles have coarse stems, much seed and generally an inferior quality of lupulin. Such hops are usually of low grade. Hops with medium-size strobiles are of average quality. Hops with small jointed and round strobiles have few seeds and much lupulin. The better English hops are an exception; they have large strobiles and many seeds, but a fine, delicate and bitter aroma.

Breuer (4) states that good hops should consist of large burrs with but little seed. The lupulin of superior hops viewed under the microscope is of a yellowish-green color rather than yellow.

According to Coke (6) silky luster, conical shape, greenish-golden or yellow color, and small sized cones are characteristics of good quality hops.

The factors which may affect hop quality were listed by Horst (16) as plant selection, soil class, climatic conditions, water conditions, fertilizer, diseases and insects, seed content, pruning of vines, picking at proper stage of maturity, drying temperature, and use of sulphur.

Tests by Kolbach, Rehberg and Wilharm (17) showed that the alpha-bitter and total soft-resin contents appear to increase in the hop plant until it reaches the state of full maturity. The alpha-bitter acid increases strongly in the two weeks preceding full maturity and then gradually declines. The beta-bitter acid and total soft-resin contents increase more slowly toward maturity and decline similarly. Bittering power showed a parallel change. The percentage of resins was highest in hops picked early, declined toward maturity, and then increased again.

Laufer, (18) found that hops contribute considerably to the color of wort and beer. Generally, old or dark hops produce a greater color increase than fresh and pale hops. The color contributed by hops is due almost entirely to constituents other than hop resins.

Naatz (21) suggests that when the boiling period is very short, there is a possibility that a layer of hard resin around the soft resin may impede the solution of the soft resins by the wort.

The esters are regarded as the constituents of most importance in affecting the odor of hops. The volatile oil of hops has been shown to consist chiefly of the terpene myrcene, the heptoic, octoic, and nonoic acid esters of the alcohol myrcenol, and the sesquiterpene humulene, with traces of free acids, formaldehyde, and probably some free alcohols. Rabak (23) found that the oils of imported hops were conspicuous because of their constantly lower ester content. No conclusions were drawn as to the relationship between quality and ester value.

Rabak (26) states that seeds, leaves, and stems not only affect the quality of hops unfavorably in direct proportion to the percentage of these substances contained in them, but also add useless weight to hops. Seeds have been shown to contain useless soluble extractive matter which enters the wort. Also, the partially rendered fatty oil from the seed may, due to subsequent rancidity, have an undesirable affect on the foam retention qualities of the finished beverages. Leaves and stems contain soluble extractive matter which likewise enters the wort and is likely to impart undesirable color and flavor to it.

Rabak (27) observed that hops which contained a relatively high percentage of seeds were distinctly lacking in flowery aroma.

Doerell (7) noted beneficial effects of sodium nitrate on an already rich hop garden soil. Maximum increases in total yield were obtained when the second dressing of nitrate was given between flowering and the formation of the hop. Best quality hops were produced when the dressing was administered in the period between hop formation and half growth. The phosphorus content of hop ash was not appreciably affected by manurial treatment; the protein content, on the other hand, was increased by top dressing with nitrate to extents which increased with the lateness of the application.

Experiments by Fore (10, 24) conducted on Chehalis sandy loam, a fairly fertile river bottom soil, failed to give very marked responses to fertilizers. There seemed to be some evidence that fertilizers such as ammonium sulphate, calcium nitrate, and calcium cyanamid, increase the percent of soft resins and hence the quality of the hop. Increased yields were obtained with the Late Cluster variety in fertilizer trials with fertilizers containing nitrogen and phosphorous.

Harlan (13, 14) associates quality with low yield in hops. He states that superior quality hops are produced in interior countries, and likens the quality of hops produced in New York to that of hops imported from Germany, Czechoslovakia and Yugoslavia which, like New York, are characterized by low production per acre and high quality.

Pozen (22) found that there was, in general, no clear distinction between the chemical composition and brewing values of domestic and imported hops.

Stockberger (30, 31) presents the viewpoint that too much importance is attached to geographical origin of hops.

Investigations by Tartar and Pilkington (32) indicated that commercial fertilizers tested could not be used profitably in the culture of hops in the Willamette valley. Barnyard manure was the best fertilizer of those tested.

MATERIALS AND METHODS

MATERIALS

Four samples from each variety-fertilizer-irrigation treatment were obtained in 1941 from the experimental hop yard of the Oregon Agricultural College Experiment Station. There were eight fertilizers, two varieties, and two irrigation treatments, making a total of 32 variations from which 128 samples were selected. These samples were obtained through the kindness of Dr. R. E. Fore. The two varieties were Late Clusters and Fuggles. Half of each of these was irrigated and half non-irrigated. Each of these subdivisions was then given eight different fertilizer treatments. The fertilizer treatments were as follows:

Treatment	Rate of Application	
	Per Hill	Per Acre
None (Check)	0 pounds	0 pounds
Superphosphate	2/3 "	453 "
Treble Phosphate	1/4 "	170 "
Cyanamid (As Fert.)	1/8 "	85 "
None (Check)	0 "	0 "
Complete Fertilizer	1/3 "	227 "
Cyanamid (Crown Treat.)	1/8 "	85 "
Ammophos	1/4 "	170 "

The ingredients used in making up the complete fertilizer were ammophos and muriate of potash. They were mixed in proportions to give a 9-39-9 analysis.

Each plot had received the same treatment in the years 1939, 1940, and 1941.

The fertilizers were applied at the specified rates in a ring around the plant (radius of approximately one foot) with the exception of the cyanamid applied as a crown treatment, when the fertilizer was spread evenly over the crown of the plant in a circle approximately two feet in diameter.

Additional samples analyzed in 1941 included samples submitted by hop growers and dealers to the Oregon State College Hop Analytical Laboratory. These samples were from hops grown in the three coast states. Fifty samples were selected at random to represent the hops of each of these states. Professor J. D. Harlan kindly supplied seventeen samples of New York hops.

The hops analyzed in 1940 included samples of commercial hops from each of the coast states and one lot, selected with a view to obtaining hops of inferior quality, which was obtained from the Oregon Agricultural Station experimental hop yard.

METHODS OF PHYSICAL ANALYSIS

Various physical characters or factors have long been considered as having some effect on the quality of hops. Generally speaking, however, the degree of this effect has never been determined nor has any standard weight been attached to the characters in order that individuals might adjudge quality of hops on the same basis.

The physical factors which have been measured or estimated in the course of this investigation are:

X_1 - Seeds

X_2 - Stems and Leaves

X_3 - Strigs

X_4 - Aroma

X_5 - Amount of Lupulin

X_6 - Color and Condition of Lupulin

X_7 - General Appearance

X_8 - Color (Hue)

X_9 - Broken Cones

With the exception of a standard procedure for determining the percentage of seeds, leaves and stems, and strigs developed by Monroe and Hill (20) there are no uniform accepted methods for evaluating the physical factors

The methods which were developed and used during the past two years in the accumulation of the data are described in detail below.

The determinations for the first four factors considered are based on the analysis of one 20-gram sample.

The remainder of the determinations are based on a representative sample which must be large enough to permit completion of all the determinations. The color analysis requires a sample at least six inches in diameter.

1. <u>DETERMINATION OF PERCENTAGE OF LEAVES AND STEMS</u>

<u>Definition</u> - Leaves and stems shall consist of any part of the hop sample other than actual strobiles, bracts, strigs, or stems attached to the strigs which do not exceed one-half inch in length. Stems attached to the strigs which exceed one-half inch in length are broken off at a point approximately one-half inch from the base of the hop cone and included in the determination of leaves and stems.

<u>Procedure</u> - The sample is spread out on a table. Leaves and stems are removed with a forceps and weighed to 0.01 gram, and the percentage determined.

2. <u>DETERMINATION OF PERCENTAGE OF BROKEN CONES</u>

<u>Definition</u> - Broken cones shall consist of the loosened bracts and any other parts of cones consisting of less than one-half of a whole cone.

<u>Procedure</u> - After the leaves and stems have been removed from the twenty-gram sample, the whole cones are separated from the broken cones. The broken cones are weighed to 0.1 gram, and the percentage determined.

3. and 4. <u>DETERMINATION OF PERCENTAGE OF SEEDS AND STRIGS</u>

<u>Definition</u> - Seeds shall consist of the ripened or unripened hop seeds. Strigs shall consist of the core of the strobile after the seeds and bracts have been removed. The strig is sometimes referred to as the rachis.

Procedure - After determining the percentage of broken cones, the whole and broken cones are lumped together again for determining the percentage of seeds and strigs. The sample is then placed in a 16" x 16" square of cheesecloth or muslin and rubbed between the hands to cause breakage of cones and bracts. The sample is washed in methyl alcohol to remove the resins. An old-fashioned hand wringer was rigged up to aid in wringing the alcohol out of the sample in order to conserve alcohol and to hasten drying. The samples are dried on a jacket-type dryer, designed to fit over an ordinary steam radiator. The speed of drying was increased by forcing air through at a faster rate with an electric fan.

When the drying process is complete, the samples are threshed by rubbing between the hands until all the bracts are pulverized. Care is necessary to avoid breaking up the strigs. The sample is then run over a "Clipper" Grain, Seed, and Bean Cleaner equipped with screens which allow the seed and small particles of strigs to drop into one compartment. The pulverized chaff is removed by the current of air from the fan.

The seeds can then be separated from the strigs by taking advantage of the fact that the seeds are round and will roll down an inclined plane more easily than the strigs when a rocker-motion is used to stimulate movement. The seeds and strigs are then weighed separately to 0.01 gram, and the percentages determined.

5. ESTIMATING THE VALUE OF AROMA

Definition - Aroma, as used in this study, consists of the sum total of all the odoriferous elements of the hop sample resulting in some stimulus to the olfactory system. Hence, aroma is influenced by the condition and amount of volatile oils, the presence of molds and mildew, the age and dryness of the hops, the maturity of the hops, and many other contributing factors.

Procedure - Aroma is evaluated on a scale of 0-9 with 0 being the poorest possible and 9 the best score possible. A small handful of the sample is rubbed briskly between the hands. The value of aroma is determined on the basis of the odors exuded under these conditions. Considerable practice in distinguishing differences in aroma is required before any degree of accuracy is attained. The evaluation of aroma is on the basis of whole numbers.

6. ESTIMATING THE AMOUNT OF LUPULIN

Definition - The lupulin consists of the resinous globules distributed throughout the hop cone but mainly at the bases of the bracts and along the strig.

Procedure - The amount of lupulin is evaluated on a scale of 0-9 with 0 being the poorest and 9 the best score possible. Ten cones are selected at random from the sample. Each of these is split longitudinally and the amount of lupulin observed with a 7X hand lens. The evaluation of the amount of lupulin in each cone is made in terms of whole numbers. The individual evaluations are summated and the total divided by ten to give the estimation of the amount of lupulin for the sample. Thus, the estimation of the amount of lupulin may vary from 0.0 to 9.0 by tenths.

Note: The estimation of the amount of lupulin of all the 1940 samples and the 1941 New York samples was based on the observation of only a few cones and in terms of whole numbers.

7. ESTIMATING THE VALUE OF COLOR AND CONDITION OF THE LUPULIN

Definition - Evaluations of color and condition of lupulin shall be based on the color of the globules of lupulin and their apparent stickiness when rubbed between the fingers.

Observations on the color and condition of the lupulin of hops after different lengths of storage indicate that highest quality of lupulin is represented by a bright, lemon-yellow color and a somewhat translucent appearance. The lupulin in this condition is very sticky. As deterioration and aging progresses, the color gradually becomes darker approaching a dark, brownish-orange in old hops. The lupulin globules tend to assume a smooth semi-transparent character and become less sticky as the deterioration proceeds. The rate of deterioration depends on conditions of storage including light, temperature, moisture, and compression of baling, and the length of time the hops have been stored.

Procedure - This value is also determined on a scale of whole numbers ranging from 0 to 9. The evaluation is based on a combination of the impressions obtained from observation of the lupulin with a binocular microscope under a fluorescent light and the degree of stickiness as determined by rubbing the cones between the fingers.

8. ESTIMATING THE VALUE OF GENERAL APPEARANCE

Definition - The factor, general appearance, shall include those characteristics of the sample affecting "eye appeal". The points considered include uniformity of the sample, mildew damage, red spider damage, mold damage, discolorations due to wind whip, drying, storage, etc., lustre, presence of dirt, and any other factors which have not been considered elsewhere, but may affect the appearance of the hop sample. This factor, therefore, serves as a "catch-all" making provision for any unusual features of the sample which may influence its quality.

Procedure - General appearance is evaluated in terms of whole numbers from 0 to 9. Each sample is scored on the basis of the appearance of a section from the center of the sample.

9. DETERMINATION OF COLOR (HUE)

Definition - The color values listed in these studies are in terms of hue based on the Color Conversion Tables of the United States Department of Agriculture for color readings measured with the Munsell Color Machine.

Procedure - Two determinations, one on each side of the sample, were made on each sample. The color rating is based on the average of the two determinations. The Color Conversion Tables convert hue into a numerical scale ranging from 0.0 to 10.0. A color value of 0.0 indicates no green color present, and one of 10.0 indicates the absolute maximum of green possible.

Note: Color determinations on the 1940 hop samples are based on only one reading for each sample.

METHODS OF CHEMICAL ANALYSIS

All chemical determinations were made by the Agricultural Chemistry Department of Oregon State College.

The chemical factors measured in these studies are:

Y_1 - Total Resin

Y_2 - Total Soft Resin

Y_3 - Alpha Soft Resin

Y_4 - Beta Soft Resin

Y_5 - Gamma Hard Resin

Y_6 - Preservative Value (P.V.)

The chemical determinations on the 1940 hop samples were obtained using the standard gravimetric procedure in use at the Oregon Agricultural College Experiment Station, and with slight modification, the proposed official method of the American Society of Brewing Chemists. With the exception of the samples from the Oregon State College Experimental Yard, all 1941 samples were analyzed by the same procedure. The Oregon State College samples for 1941 were analyzed using a modified procedure of a colorimetric method of analysis proposed by Alderton (1).

The preservative value was calculated on the basis of the formula:

$$P.V. = \left[\text{Alpha Resin} + \frac{\text{Beta Resin}}{3} \right] \times 10.$$

THE NECESSITY FOR THE DEVELOPMENT OF METHODS OF PHYSICAL ANALYSIS

The annual hop crop of the United States is approximately 240,000 bales. A sampling study to determine what proportion of the bales of a given lot of hops must be sampled in order to get a representative sample of the lot is now under way. At present it is not possible to state definitely what this proportion will be. The variability of the lot will be one influencing factor. But, if every tenth bale were sampled, it would be necessary to analyze 24,000 samples each year. Or, with every hundredth bale, it would be necessary to analyze 2,400 samples each year. The number of samples which must be analyzed in a given period of time, the type of labor required for the analysis, and the equipment and facilities necessary are all factors which must be considered before a system of grades can be established.

The chemical analysis to determine the resin content of hops has been considered to be the final criterion of hop quality by dealers and brewers.

The gravimetric procedure of chemical analysis for hop resins would be of limited value in a commercial grading program because of its slowness and relatively high cost per sample. The experience of the chemists at the Oregon Agricultural Experiment Station has shown that one man, with an assistant to grind samples, can analyze only six samples a day by the gravimetric procedure. Using the colorimetric method of analysis, it is possible to triple this number. It is essential to have a fairly complete chemical laboratory and the work must be done by an experienced technician.

Subsequent data and discussion indicate that the methods of physical analysis which are used in the study have considerable value in estimating or predicting the resin content of hops. After two years experience using the methods, the author is of the opinion that the procedures could be sufficiently standardized, so that one well trained technician, with the assistance of three unskilled (but adept) helpers could run a complete physical analysis on 100 samples a day.

An indication of the accuracy of the methods of analysis is given by the averages for the four replicates in Table 6. There is little doubt that it would be fairly easy to train unskilled workers to do the work required to make most of the determinations with the necessary degree of accuracy.

METHODS OF STATISTICAL ANALYSIS

The methods used in deriving the statistics used in this paper are described in detail by Fortmann and Huggins (9). The reader is also referred to Ezekiel(8) and Goulden (11).

For the sake of convenience, a brief resume' of the statistics used, their meaning and significance and the formulas used in their derivation is included at this time.

TERMINOLOGY

Statistic - Any figure derived from the data analyzed which expresses some relationship between the various components of the data or in some way describes the data, e.g. average, correlation coefficient, etc.

Variate.- One individual measurement of any given character or property being studied.

Variable - Any character or property being studied and measured. If the magnitude is not considered as being influenced by any of the other characters, it is called an independent variable. If, however, it is thought that the character is influenced by certain of the other characters, it is called a dependent variable. In these studies, the physical factors measured are considered independent variables and the chemical factors are dependent variables.

Average or Mean ($\bar{X}_i$ And $\bar{Y}_i$) - The total of all the measurements in a given series of any one variable under consideration divided by the number of measurements.

Formula: (1)

$$\bar{X}_i = \frac{\Sigma X_i}{N}$$

This formula will be used in the calculation of $\bar{Y}_i$ substituting Y for X wherever it occurs. This applies to all succeeding forumlas that are solved from both Y and X.

Standard Deviation (Sd) - A statistic which describes or measures the variation of the variates around the mean or average in any particular group of measurements. It means that approximately 66% of the measurements fall within a range of ± that figure to the average for the group. Thus with seeds for the 1940 Washington data found in Table 9, the average = 10.36 and the Sd = 4.027. In 66% of the cases, the percent of seeds for the 51 samples falls within a range ± 4.027 of 10.36.

Formula: (2)

$$Sd\ X_i = \frac{\sqrt{\Sigma x_i^2}}{\sqrt{N - 1}}$$

The above formula is based on the data after it has been corrected about the mean (or the correction factor has been subtracted from the original sums of squares).

Correlation Coefficient (r) - A statistic which measures the relative relationship between two variables. It is never more than + 1.0000 and never less than - 1.0000. If the correlation coefficient is positive (+), it means that the two variables tend to vary up and down together. That is as one increases the other also increases, and as one decreases, the other also decreases. A negative (-) correlation coefficient, on the other hand, indicates that as one variable increases, the other decreases and vice versa.

The correlation coefficients are found in Tables 9 and 10. The correlation coefficient between any two variables will be found at the junction of a line extending vertically from one variable at the top of the page and another horizontally from the other variable at the left side of the page.

Significant correlation coefficients are indicated by the use of ^{x} or ^{xx}. One ^{x} indicates that that particular correlation coefficient is significant at the 5% level. This means that the odds are 19 to 1 against a correlation coefficient that large occurring by chance with the number of data involved. Two x's indicate that that correlation coefficient is significant at the 1% level. This means that the odds are 99 to 1 against a correlation coefficient that large occurring by chance with the number of data involved.

A statisically significant correlation coefficient does not necessarily prove a casual relationship between any two variables. A third or unknown variable may effect the two in such a way as to establish a correlation between the two. Another point to be considered is that statistical significance does not necessarily imply practical significance.

The size of the correlation coefficient indicates the consistency with which two variables vary together in the case of a positive correlation, or vary apart or inversely in the case of a negative correlation. Therefore, the size of the correlation coefficient is very important in interpreting the data. The larger the correlation coefficient, the more conclusive the relationship.

Formula: (3)

$$r \text{ between } X_i \text{ and } X_k = \frac{\Sigma x_i x_k}{\sqrt{\Sigma x_i^2}\sqrt{\Sigma x_k^2}}$$

To get the correlation coefficient between x_i and y_i, y_i will be substituted for x_k in the above formula.

The formula used to provide a means of measuring how large a correlation coefficient must be with a given set of data, in order that it may be statistically significant is given for the 5% level. "t" at the 1% level may be substituted into the equation to get the r for the 1% level.

Formula: (4)

$$r_{.05 \text{ level}} = \frac{t_{.05 \text{ level}}}{\sqrt{N + t^2_{.05 \text{ level}}}}$$

"t" is evaluated at N - 2 degrees of freedom as found in Table 94 in Goulden's "Methods of Statistical Analysis" (11).

Regression Coefficient (b) - A statistic which measures the absolute relationship existing between an independent variable and a dependent variable in a given set of data. The regression coefficient tells us the number of units or the fraction of a unit that the dependent variable is going to increase, on the average, with each unit increase of the independent variable, all other independent variables remaining constant.

The regression coefficients for the 1940 data were calculated using Doolittle's method. In 1941 a new method of calculating regression coefficients was devised. This method is based on Crout's method for evaluating determinants and solving systems of linear equations. The method is described in detail in reference (9). The regression equation based on the regression coefficients calculated by this method appears as:

Formula:

$$
\begin{aligned}
Y_i - \bar{Y}_i = \; & b_{Y_iX_1 \cdot X_2X_3X_4X_5X_6X_7X_8X_9} (X_1 - \bar{X}_1) \\
+ \; & b_{Y_iX_2 \cdot X_1X_3X_4X_5X_6X_7X_8X_9} (X_2 - \bar{X}_2) \\
+ \; & b_{Y_iX_3 \cdot X_1X_2X_4X_5X_6X_7X_8X_9} (X_3 - \bar{X}_3) \\
+ \; & b_{Y_iX_4 \cdot X_1X_2X_3X_5X_6X_7X_8X_9} (X_4 - \bar{X}_4) \\
+ \; & b_{Y_iX_5 \cdot X_1X_2X_3X_4X_6X_7X_8X_9} (X_5 - \bar{X}_5) \\
+ \; & b_{Y_iX_6 \cdot X_1X_2X_3X_4X_5X_7X_8X_9} (X_6 - \bar{X}_6) \\
+ \; & b_{Y_iX_7 \cdot X_1X_2X_3X_4X_5X_6X_8X_9} (X_7 - \bar{X}_7) \\
+ \; & b_{Y_iX_8 \cdot X_1X_2X_3X_4X_5X_6X_7X_9} (X_8 - \bar{X}_8) \\
+ \; & b_{Y_iX_9 \cdot X_1X_2X_3X_4X_5X_6X_7X_8} (X_9 - \bar{X}_9)
\end{aligned}
$$

Using the regression equation above, it is possible to estimate the magnitude of a given Y or dependent variable within a range ± the standard error of estimate of the measurement that would be obtained by chemical analysis at least 66% of the time.

Standard Error of Estimate (Se) - Is a statistic which measures the accuracy with which it would be possible to predict the dependent variable in the regression equation. In this case, it measures the accuracy with which one can predict the magnitude of any particular chemical factor using measurements of certain of the physical factors.

Formula: (6)

$$Se = \sqrt{\text{Unadjusted error variance}}$$

Multiple Correlation Coefficient (R) - A statistic which measures the combined relationship between a dependent variable and a series of independent variables. In the case of the 1940 analysis, this is a measure of the relationship between 3 or 4 of the most significantly correlated independent variables and the dependent variable. In the case of the 1941 analysis, it measures the combined relationship between all nine of the independent variables and the dependent variable. R is the measure of the relationship that exists in the samples analyzed for any given lot.

Formula: (7)

$$R = \sqrt{\frac{\text{Sum of Squares of Regression Equation}}{\text{Total Sum of Squares}}}$$

Multiple Correlation Coefficient ($\bar{R}$) - This statistic is a refinement of R. It measures the relationship which will exist between the independent variables used and the dependent variable in the entire population of samples in the universe.

Formula: (8)

$$\bar{R} = \sqrt{R^2 \left[1 - \frac{\text{Error Variance}}{\text{Variance of Regression Equation}}\right]}$$

R^2 or $\bar{\bar{R}}^2$ multiplied by 100 expresses the percentage of the variation of the dependent variable that is accounted for by the independent variables used in the regression equation.

Calculated F Value - Is the statistic which expresses the ratio between the variance accounted for by any given factor and the error variance. It is used as a measure of significance. The size of the F value necessary for significance at the 5% and 1% levels is dependent on the degrees of freedom for each of the components. A table of the F values required for significance for the various degrees of freedom can be found in most texts on statistics.

Formula:

$$F = \frac{\text{Factor Variance}}{\text{Error Variance}}$$

Minimum Significant Difference (M.S.D.) - This statistic measures the difference that must exist between treatment means or variety means in order that the difference be statistically significant. It differs from the F value in that the F value merely indicates that significant differences do or do not exist, whereas M.S.D. indicates the size of the difference that must exist for significance. M.S.D. is not calculated if the F value is not significant. Table 8 gives the M.S.D.'s required for significance of differences between the means in Tables 2 to 5 inclusive.

Formula:

$$\text{M.S.D.} = \left[\sqrt{\frac{\text{Error Variance X 2}}{\text{No. of Variates in one of the Means compared}}} \right] \text{X } t_{.05}$$

The t value may be at the .05 or the .01 level for the error degrees of freedom.

THE EFFECT OF VARIETY, IRRIGATION TREATMENT, AND FERTILIZER TREATMENT ON THE PHYSICAL AND CHEMICAL FACTORS MEASURED

The data in this section are based on the analysis of the samples obtained in 1941 from the experimental hop yard of the Oregon Agricultural Experiment Station. A complete summary of the information is recorded in Tables 1 to 8 inclusive. All the sources of variation were not replicated in the design of the experiments from which these samples were obtained. In order to overcome this, four samples were taken from each plot. These samples are treated as though they were bona-fide replicates. The variance for the interaction, Varieties X Irrigation Treatments X Fertilizer Treatments, was used as the error variance in the calculation of the F values found in Table 7.

The average analyses for each of the four-sample treatments are given in Table 1. The means for each variety-irrigation treatment found in Table 2 are used to measure the interaction between varieties and irrigation treatment. Table 3 contains the average analyses for fertilizer treatments. Irrigation treatment averages are given in Table 4. The average analyses for varieties are given in Table 5.

TABLE 1: AVERAGE ANALYSIS OF FOUR-SAMPLE REPLICATES: O.S.C. 1941:

CULTURAL TREATMENT		FERT.	SEEDS	LEAVES STEMS	STRIGS	AROMA	AMOUNT LUPULIN	COND. LUPULIN	GENERAL APPEAR.	COLOR HUE	BROKEN CONES	SOFT RESIN	ALPHA RESIN	BETA RESIN	[-60]+10 P.V.	NO.
			VARIABLES USED FOR ALL TABLES													
IRRIGATED	FUGGLES	1	13.8	2.0	8.0	4.2	3.2	6.0	7.0	8.88	34.1	14.1	4.0	10.1	1.35	4
		2	11.8	5.0	7.5	3.0	4.6	6.2	6.7	9.21	39.4	13.3	3.6	9.7	0.88	4
		3	12.1	4.1	7.9	3.7	4.2	5.0	5.7	9.00	34.2	13.4	3.9	9.4	1.10	4
		4	12.5	1.2	8.0	4.0	4.8	6.0	6.0	8.92	53.0	13.5	4.0	9.5	1.18	4
		5	13.0	1.4	7.9	4.7	4.8	6.0	6.0	8.31	30.6	15.4	5.0	10.4	2.48	4
		6	11.8	0.4	8.9	3.7	3.6	6.0	6.7	9.67	42.2	14.5	4.8	9.7	2.02	4
		7	10.1	1.5	7.8	4.7	3.8	7.0	6.7	8.77	31.9	14.2	4.2	9.8	1.55	4
		8	9.9	2.7	7.8	5.2	3.0	6.7	7.0	8.52	25.6	13.5	4.0	9.4	1.20	4
	LATE CLUSTER	1	7.6	1.2	8.1	6.5	7.4	7.0	6.7	8.65	47.5	15.6	5.9	9.6	3.12	4
		2	4.3	1.0	9.5	6.0	7.4	6.7	7.2	8.97	46.9	15.7	5.6	10.0	3.05	4
		3	6.5	1.4	9.3	7.2	7.2	7.0	7.0	8.64	43.7	14.8	5.5	9.3	2.68	4
		4	8.1	1.0	8.1	7.0	7.4	7.5	7.0	8.85	46.4	16.1	6.3	9.8	3.55	4
		5	6.0	1.5	5.8	5.7	5.6	6.0	7.0	9.01	60.0	13.5	4.8	8.7	2.00	4
		6	5.0	1.6	4.0	6.5	6.7	6.7	6.7	8.82	52.7	15.4	5.8	9.6	3.00	4
		7	12.5	0.9	13.7	7.0	7.2	6.7	7.0	8.57	61.5	16.6	6.0	10.6	3.58	4
		8	9.8	1.4	10.7	6.7	7.7	7.2	7.0	8.90	48.7	17.8	6.8	11.1	4.45	4
NON-IRRIGATED	FUGGLES	1	10.9	4.9	8.4	7.0	4.9	6.7	6.7	7.99	51.2	13.7	4.4	9.2	1.52	4
		2	13.8	1.3	7.8	6.7	4.4	7.0	7.2	8.22	42.5	15.3	4.6	10.6	2.45	4
		3	11.4	0.9	7.0	5.5	5.8	6.0	6.0	7.98	52.0	14.2	4.5	9.7	1.70	4
		4	14.4	0.4	7.8	4.5	4.8	6.0	6.2	8.43	36.5	13.9	4.7	9.2	1.80	4
		5	12.8	1.9	6.8	3.7	4.2	6.5	6.2	8.47	42.9	14.0	4.9	9.1	1.95	4
		6	11.8	1.6	7.9	4.5	4.5	6.5	7.0	8.54	42.5	14.8	4.9	9.8	2.22	4
		7	14.1	0.7	7.9	4.2	4.3	6.0	7.0	8.75	44.4	15.8	5.4	10.4	2.85	4
		8	12.8	1.7	7.7	4.0	4.1	6.5	6.7	8.62	29.4	15.1	4.9	10.2	2.32	4
	LATE CLUSTER	1	10.3	1.3	8.4	7.7	7.5	7.7	7.2	8.86	48.7	17.8	6.8	11.0	4.50	4
		2	8.7	1.2	8.7	7.5	7.6	7.7	7.5	8.43	56.2	18.8	7.0	11.8	4.92	4
		3	7.5	1.6	9.6	7.2	7.5	7.5	7.0	8.02	41.4	17.3	6.9	10.4	4.35	4
		4	5.4	2.0	5.3	7.0	6.7	7.5	7.0	8.44	43.9	18.0	6.6	11.4	4.42	4
		5	8.8	1.3	9.8	7.5	7.0	7.0	7.0	8.94	55.0	17.8	6.8	11.0	4.45	4
		6	11.4	0.5	9.7	7.2	7.2	7.0	6.7	8.11	51.0	18.2	6.8	11.4	4.60	4
		7	11.7	0.6	8.7	6.7	6.8	7.5	7.7	9.13	55.6	17.8	6.5	11.3	4.22	4
		8	9.3	1.4	7.6	4.2	7.1	7.0	6.2	7.25	50.1	16.7	5.7	10.8	3.48	4

TABLE 2: AVERAGE ANALYSIS OF IRRIGATION-VARIETY SAMPLES:

IRRIG. FUGGLES	11.89	2.31	8.00	4.19	4.00	6.12	6.50	8.91	36.39	13.98	4.21	9.74	1.47	32
IRRIG. LATE CLUST.	7.52	1.24	8.66	6.59	7.08	6.88	6.97	8.81	50.94	15.69	5.85	9.85	3.18	32
NON-IRRIG. FUGGLES	12.78	1.67	7.68	5.03	4.61	6.41	6.66	8.38	42.67	14.61	4.79	9.79	2.10	32
NON-IRRIG. L.C.	9.15	1.25	8.51	6.91	7.20	7.38	7.06	8.40	50.25	17.79	6.66	11.12	4.37	32

TABLE 3: AVERAGE ANALYSIS OF FERTILIZER TREATMENT SAMPLES:

NO FERTILIZER	10.68	2.34	8.25	6.38	5.75	6.88	6.94	8.59	45.41	15.29	5.30	9.99	2.62	16
SUPERPHOSPHATE	9.65	2.10	8.46	5.81	6.00	6.94	7.19	8.71	46.25	15.78	5.20	10.56	2.82	16
TREBLE-PHOS.	9.41	2.01	8.46	5.94	6.19	6.38	6.44	8.41	42.84	14.92	5.22	9.70	2.46	16
CYANAMID [FERT.]	10.11	1.16	7.32	5.62	5.92	6.75	6.56	8.66	44.94	15.38	5.40	9.96	2.74	16
NO FERTILIZER	10.18	1.54	7.59	5.44	5.38	6.38	6.56	8.68	47.12	15.19	5.39	9.79	2.72	16
AMMOPHOS	9.99	1.04	7.64	5.50	5.52	6.56	6.81	8.79	47.12	15.70	5.58	10.11	2.96	16
COMPLETE FERT.	12.18	0.94	9.53	5.69	5.53	6.81	7.12	8.81	48.34	16.08	5.52	10.52	3.05	16
CYANAMID [CR.TR.]	10.49	1.82	8.45	5.06	5.48	6.88	6.75	8.33	38.47	15.79	5.40	10.36	2.86	16

TABLE 4: AVERAGE ANALYSIS OF IRRIGATED AND NON-IRRIGATED SAMPLES:

IRRIGATED	9.71	1.77	8.33	5.39	5.54	6.50	6.73	8.86	43.66	14.83	5.03	9.79	2.32	64
NON-IRRIGATED	10.96	1.46	8.10	5.97	5.90	6.89	6.86	8.39	46.46	16.20	5.72	10.45	3.24	64

TABLE 5: AVERAGE ANALYSIS OF VARIETIES:

FUGGLES	12.33	1.99	7.84	4.61	4.31	6.21	6.58	8.64	39.53	14.29	4.50	9.77	1.78	64
LATE CLUSTERS	8.34	1.24	8.58	6.75	7.14	7.12	7.02	8.60	50.59	16.74	6.25	10.48	3.77	64

TABLE 6: REPLICATE AVERAGES AND GRAND AVERAGE:

REPLICATE A	10.51	1.49	8.25	5.66	5.78	6.66	6.72	8.55	45.52	15.45	5.41	10.03	2.77	32
REPLICATE B	10.29	1.82	8.21	5.75	5.61	6.72	6.84	8.69	46.42	15.54	5.38	10.15	2.85	32
REPLICATE C	10.49	1.47	7.98	5.81	5.80	6.72	6.94	8.67	43.02	15.73	5.46	10.23	2.89	32
REPLICATE D	10.05	1.69	8.40	5.50	5.70	6.69	6.69	8.58	45.30	15.34	5.25	10.08	2.61	32
GRAND AVERAGE	10.335	1.618	8.212	5.680	5.722	6.695	6.797	8.623	45.062	15.514	5.376	10.124	2.779	128

TABLE 7: ANALYSIS OF VARIANCE [TABLE OF CALCULATED F VALUES FOR SOURCES OF VARIATION]

															F.05	F.01
VARIETIES	31.32	4.12	1.39	36.75**	434.34**	29.92**	12.02**	.08	18.49**	47.28**	105.26**	16.00**	92.75**	64	4.32	8.02
IRRIGATION TR.	3.09	.63	.14	2.68	7.24*	6.19*	.98	10.00**	1.18	14.71**	16.69**	13.70**	19.60**	64	4.32	8.02
INTERACTION [V X I]	.27	.28	.02	.56	30.44**	.47	.06	.18	1.83	4.28	.43	11.59**	1.82	64	4.32	8.02
FERTILIZERS	.71	.93	.62	.60	2.27	1.05	2.33	.66	.75	.58	.31	1.66	.44	16	2.49	3.65

TABLE 8: TABLE OF M. S. D. [CALCULATED ONLY WHEN THE F VALUE IS SIGNIFICANT]

VARIETIES	1.48			.73	.28	.33	.26		4.47	.74	.35	.37	.43	0.05 LEVEL
VARIETIES	2.01			.99	.38	.45	.35		6.08	1.00	.48	.50	.58	0.01 LEVEL
IRRIG. TREAT.					.28	.33		.33		.74	.35	.37	.43	0.05 LEVEL
IRRIG. TREAT.					.38	.45		.45		1.00	.48	.50	.58	0.01 LEVEL
INT. [V X I]					.40							.53		0.05 LEVEL
INT [V X I]			H.R.F.	3-6-42	.54							.71		0.01 LEVEL
FERT. TREAT.														0.05 LEVEL
FERT. TREAT.														0.01 LEVEL

It should be mentioned that the P.V. which is recorded in the tables is a figure obtained from data coded for the convenience of calculation. Thus the listed P.V. is obtained from the actual P.V. by the following formula:

$$\text{Listed P.V.} = \frac{(\text{P.V.} - 60)}{10}.$$

To decode the listed P.V. simply use the formula:

$$\text{P.V.} = (10 \times \text{Listed P.V.}) + 60.$$

THE EFFECT OF VARIETIES ON THE FACTORS ANALYZED

The seed content of the Fuggles variety is significantly higher than that of Late Clusters. The difference is significant at the 1% level.

There are several theories which may be advanced to explain this difference. The difference may be accounted for on the basis that conditions for pollen formation and pollination were favorable during the period when the Fuggles variety was setting seed. Another possibility is that more of the males in the yard corresponded in their development with that of the Fuggles variety than with the Late Clusters. A third explanation rests on the fact that the Late Clusters variety produces cones which are larger than the Fuggles. Thus, although the same number of seeds may have been produced, the percentage would be smallest in the case of the variety with the largest cone size. Future investigations may be developed with a view to establishing evidence to explain the difference in seed content of the two varieties.

The Late Clusters variety has the highest average analysis in the case of aroma, amount of lupulin, color and condition of lupulin, general appearance, percentage broken cones, and all four of the chemical factors analyzed. In every case the difference that exists is significant at the 1% level.

The facts that the average color analysis for the Fuggles is only very slightly higher than that for Late Clusters and that Fuggles have a higher seed content lend support to the theory that the differences which exist are not due to a difference in maturity at time of picking but rather to inherent differences in the two varieties.

Significant differences occur between the aroma of the two varieties. It is believed that a large part of this difference may be attributed to differences in the length of storage under adverse conditions. The Fuggles variety was picked earliest and the samples were stored in the Experiment Station hop dryer until all varieties had been picked and baled. All samples were then placed in cold storage.

It is doubtful if the differences observed in the factor general appearance have much practical significance.

One explanation which may be offered to explain the difference observed in the percentage broken cones is the fact that the Late Clusters cones are larger and tend to be of a more open construction. They are, therefore, subject to breakage to a greater extent than the smaller, more compact Fuggles.

THE EFFECT OF IRRIGATION TREATMENTS ON THE FACTORS ANALYZED

The average color analysis of the samples from the irrigated plots is significantly higher than that for the non-irrigated samples. The difference is significant at the 1% level. On the other hand, samples from non-irrigated plots have more lupulin and a better color and condition of lupulin. These differences are significant at the 5% level. With all the chemical factors, the non-irrigated plots show the highest averages. All differences are significant at the 1% level.

The facts listed above indicate that irrigation has one or both of two effects. The first of these is that it causes an increase in the number and/or the size of cones. If there is not a corresponding increase in the amount of resins produced, the percentage must necessarily be decreased. The second possible effect of irrigation is that it causes a prolongation of the period of vegetative growth. The vines continue to grow and produce photosynthetic surface longer than they do when not irrigated. The formation and deposition of resins would seem to be associated with reaching maturity and the development of reproductive processes. A prolongation of the period of vegetative growth by the use of irrigation is thus not conducive to the production of hops rich in resins and aromatic oils.

It is interesting to note, while the differences is not significant on a statistical basis, that the non-irrigated samples have a higher average seed oontent than do the irrigated samples. This difference again may be due to the increased production of vegetative matter, or it may be due to the retardation of reproductive processes due to irrigation.

These limited observations indicate that irrigation does not have a favorable effect on quality. This statement is applicable only to conditions comparable to those existent at Corvallis, Oregon.

Fore (10) found that irrigation resulted in increases in yield of approximately 25%. This increase in yield is opposed by the higher resin content of hops produced under non-irrigation. The total soft resin content of the non-irrigated samples is 9.6% higher than that of the irrigated. The alpha resin, beta resin, and preservative value for the non-irrigated plots is 13.7%, 6.7% and 11.1% greater, respectively, than the average analyses for the irrigated plots. There will, therefore, be more resin produced per acre under irrigation, but the advantage of irrigation is not as great as seems apparent from an observation of yield data alone.

THE INTERACTION BETWEEN VARIETIES AND IRRIGATION TREATMENTS

There is a significant interaction between varieties and irrigation treatments with the amount of lupulin and the percentage of beta resin. With both of these factors the interaction is significant at the 1% level.

Both Fuggles and Late Clusters show less lupulin in the irrigated lots but the significant difference between irrigated and non-irrigated occurs in the Fuggles variety. The irrigated hops show less beta resin than the non-irrigated, although here the effect is more pronounced in the Late Cluster variety.

The explanation for the interaction, which is observed with regard to lupulin content, rests on the fact that the Fuggles are the first to be harvested. Normally, under the conditions present at Corvallis, moisture relations are such that the plant vegetative growth is retarded soon enough in the cycle of development to allow for the formation of the desirable resins. Under irrigation, vegetative growth is stimulated and continued so that when the crop is harvested at the same time as non-irrigated hops a lower percentage of resin in the hops is obtained.

It is believed that the explanation used above is also applicable to the difference in beta resin between irrigated and non-irrigated hops of the Late Cluster variety. If it is accepted that alpha resin is transformed into beta resin on aging (19, 21, 29) it will readily be seen that when the processes associated with the inception of maturity and the resultant deposition of resin are retarded or delayed, that the amount of beta resin present is probably going to be the most likely to show the greatest resultant decrease.

It will be observed that while the differences are not statistically significant, certain relationships are constant for both varieties as far as their reaction to irrigation are concerned. It is observed that irrigation results in the production of hops with a higher green color, a lower seed content, lower evaluations of amount of lupulin, color and condition of lupulin, and general appearance. The chemical analysis is lower for all factors in the irrigated hops.

THE EFFECT OF FERTILIZER TREATMENTS ON THE FACTORS ANALYZED

There are no significatn differences between any of the fertilizer treatments means. Certain of the factors, especially the chemical ones, do indicate that superphosphorous and the complete fertilizer have a beneficial effect.

The results indicate that fertilizer is not of much immediate value as far as raising and improving the quality of hops is concerned. From the standpoint of maintaining soil fertility the practice of fertilizing undoubtedly has valid merits.

Supplementary Table A shows the relative yield of three varieties of hops under the different fertilizer treatments. This table is based on unpublished data from experiments conducted by Dr. R. E. Fore at Corvallis, Oregon. It is probable that the differences which are observed would not prove to be significant if the data on which they are based could be subjected to statistical analysis.

DISCUSSION

Emphasis must be placed on the fact that the results presented here are based on only one year's data and observations. The conclusions are valid for the hop crop of 1941 for the area surrounding Corvallis, Oregon, or regions with comparable conditions. Further study will be valuable in establishing the consistency of the relationships and effects observed.

One would not expect the percentage of stems and leaves to be affected by any of the treatments considered.

SUPPLEMENTARY TABLE A

Average yields in Per Cent of the Check Plots of Various Fertilizer Trestments in Irrigated and Non-Irrigated Plots of Three Variaties of Hops

Variaty	Irrigation	Year	Check	Super Phos.	Treble Phos.	Cyanamid Fert.	Cyanamid Crown Tr.	Ammophos 11-48	Complete 9-39-9
Late Clusters	Irrigated	1939	100	99	128	77	97	132	97
		1940	100	119	125	116	109	107	138
		1941	100	96	112	132	101	96	90
		Ave.	100	105	123	105	103	114	110
	Non-Irrigated	1939	100	77	118	77	127	132	123
		1940	100	83	98	133	131	127	110
		1941	100	77	84	95	105	86	99
		Ave.	100	79	101	101	121	115	111
Fuggles	Irrigated	1939	100	84	125	72	72	116	103
		1940	100	101	123	98	106	126	103
		1941	100	111	115	95	92	110	96
		Ave.	100	99	121	87	89	116	100
	Non-Irrigated	1939	100	65	77	77	88	88	100
		1940	100	76	79	101	103	83	102
		1941	100	77	110	120	93	110	111
		Ave.	100	72	89	99	94	95	105
* Early Clusters	Irrigated	1939	100	109	91	57	67	81	101
		1940	100	83	93	74	85	86	89
		Ave.	100	96	92	68	76	83	95
	Non-Irrigated	1939	100	57	74	63	97	126	74
		1940	100	78	102	113	98	117	100
		Ave.	100	68	92	89	97	121	88
Combined Average			100	88	103	91	97	107	102

*No 1941 data for Early Clusters on fertilizer trials.unpublished data from experiments conducted by Dr. R. E. Fore at Corvallis, Oregon.

This factor is determined entirely by the care with which the hops are picked. In no case is the percentage of leaves and stems affected significantly by any of the sources of variation. This fact serves to lend confidence in the reliability of the data and the methods of analysis.

Future investigations to determine the comparison between the four most important varieties of hops, Fuggles, Early Cluster, Red Vine, and Late Clusters would be interesting. The relationship between irrigation, number of vines per hill and cone size should also be investigated. Evidence explaining the differences in seed content and resin content should be secured.

AN ANALYSIS OF THE CORRELATION BETWEEN FACTORS IN SELECTED LOTS OF HOPS IN 1940 AND 1941

1940 Data

A complete summary of the correlation analysis of four lots of 1940 hops and an analysis of the combined data is presented in Table 9. The lots consist of samples selected at random from the samples sent in for commercial analysis from the three coast states. There are 51 samples from Washington, 64 from Oregon, and 34 from California. In addition, there are 18 samples from the Oregon Agricultural Experiment Station hop yard. This made a total of 167 samples included in the analysis.

Included in Table 9 is the high and low variate for each lot, the average of all the variates in each lot and for all lots combined, and the standard deviation of a single determination for the samples of each lot and for the total. These statistics indicate the nature of the samples examined. They also are a reflection of the quality of the hops produced in the different regions in 1940. It must be remembered that the commercial samples which were included in the study were submitted voluntarily by growers and dealers themselves and were not drawn by an official sampler. The statistics just mentioned

A SUMMARY OF PHYSICAL AND CHEMICAL PROPERTIES OF SELECTED LOTS OF HOPS TOGETHER WITH CORRELATION COEFFICIENTS BETWEEN ALL CHARACTERS: 1940:

	CHARACTERS OR PROPERTIES	SEEDS	STEMS	STRIGS	AROMA	AM'T LUPUL.	COLOR & CON. LU.	GEN. APPEAR	COLOR	TOTAL RESIN	SOFT RESIN	ALPHA RESIN	BETA RESIN	HARD RESIN	P.V.
HIGH VARIATE	WASHINGTON	19.5	12.8	12.2	9	9	9	9	8.7	22.3	21.1	8.7	13.9	1.6	127.0
	OREGON	16.5	13.0	12.5	9	8	8	8	8.0	21.4	20.2	9.4	13.4	2.3	126.0
	CALIFORNIA	9.3	8.7	12.8	9	9	9	9	9.2	23.8	22.6	9.8	12.8	1.7	140.0
	O.S.C. EXPER.	23.5	1.5	14.2	8	9	9	9	7.1	24.8	23.1	8.2	16.3	2.6	128.0
	ALL SAMPLES	23.5	13.0	14.2	9	9	9	9	9.2	24.8	22.6	9.8	16.3	2.6	140.0
LOW VARIATE	WASHINGTON	0.5	1.5	4.8	3	4	6	6	6.0	15.0	14.2	4.6	8.6	0.8	78.0
	OREGON	0.0	1.0	5.5	4	5	5	5	5.6	16.6	15.4	5.6	8.8	1.0	93.0
	CALIFORNIA	0.1	1.6	4.6	5	5	6	5	4.8	13.7	12.6	4.2	8.2	1.0	70.0
	O.S.C. EXPER.	11.0	0.3	8.7	1	7	4	2	2.1	20.0	18.8	4.5	11.8	1.1	95.0
	ALL SAMPLES	0.0	0.3	4.6	1	4	4	2	2.1	13.7	12.6	4.2	8.2	0.8	70.0
AVERAGE OF ALL VARIATES	WASHINGTON	10.36	5.82	8.84	7.45	6.86	7.88	8.16	7.31	18.41	17.17	6.29	10.88	1.24	100.4
	OREGON	5.84	6.50	9.22	7.34	6.92	6.88	6.97	7.02	19.14	17.91	7.31	10.61	1.23	108.4
	CALIFORNIA	2.39	4.58	7.56	7.47	7.24	7.15	8.00	7.58	17.52	16.12	6.53	9.58	1.38	97.2
	O.S.C. EXPER.	17.62	0.68	11.42	3.44	7.89	7.56	6.67	4.58	22.39	20.79	6.54	14.25	1.61	113.0
	ALL SAMPLES	7.79	5.27	9.00	6.98	7.07	7.16	7.51	6.96	18.94	17.63	6.76	10.88	1.33	103.8
STANDARD DEVIATION	WASHINGTON	4.077	2.771	1.342	1.137	1.020	0.937	0.903	0.655	1.391	1.346	0.772	0.984	0.218	8.640
	OREGON	4.299	3.062	1.390	0.801	0.762	0.976	0.908	0.512	1.129	1.106	0.909	0.959	0.220	8.650
	CALIFORNIA	2.170	1.858	1.678	0.896	1.046	0.744	0.985	0.919	1.965	1.931	1.108	0.963	0.167	13.440
	O.S.C. EXPER.	3.559	0.369	1.707	2.727	0.758	1.504	2.275	1.261	1.300	1.339	0.853	1.361	0.358	8.200
	ALL SAMPLES	3.775	2.563	1.461	1.247	0.990	0.994	1.132	0.748	1.147	1.391	0.901	1.007	0.227	9.680

CHAR.	ORIGIN	HIGH	LOW	AVE.	CORRELATION COEFFICIENTS													
SEEDS	WASH.	19.5	0.5	10.36	1.000	.209	- 129	-.137	.154	-.093	-.413**	-.325*	.250	.286*	-.388**	.671**	-.138	-.076
	OREGON	16.5	0.0	5.84	1.000	-.066	.121	.397**	.123	.241*	.029	.074	.096	.170	-.610**	.766**	-.377**	-.348**
	CALIF.	9.3	0.1	2.39	1.000	-.109	.237	-.067	-.035	.219	-.001	-.035	-.097	-.081	-.248	.103	-.221	-.180
	O.S.C. EXP.	23.5	11.0	17.62	1.000	.553*	.199	-.089	.179	.215	-.126	-.275	.481*	.421	-.530*	.382	.184	-.143
	ALL SAMP.	23.5	0.0	7.79	1.000	.038	.065	.045	.112	.122	-.122	-.122	.140	+.175*	-.457**	.590**	-.192**	-.197**
STEMS	WASH.	12.8	1.5	5.82		1.000	-.330*	-.282*	-.143	-.514**	-.382**	-.102	-.122	-.091	-.291*	.078	-.103	-.222
	OREGON	13.0	1.0	6.50		1.000	-.153	-.127	.034	.086	-.312**	-.304*	-.289*	-.287*	-.206	-.139	.037	-.283*

AND LEAVES	CALIF.	8.7	1.6	4.58	1.000	.095	-.209	.349*	-.266	-.210	-.206	.251	.242	.231	.232	.086	.244
	O.S.C. EXP.	1.5	0.3	0.68	1.000	-.041	-.116	-.008	-.253	-.276	.099	.339	.279	-.376	.510*	.205	.099
	ALL SAMP.	13.0	0.3	5.27	1.000	-.116	-.146	.019	-.160*	-.247**	-.157*	-.089	-.080	-.140	.007	.063	-.131
STRIGS	WASH.	12.2	4.8	8.84		1.000	.171	.181	.218	-.025	.016	.120	.086	.106	.042	.191	.112
	OREGON	12.5	5.5	9.22		1.000	.006	-.084	.121	-.006	.154	.036	.023	-.056	.073	.033	-.027
	CALIF.	12.8	4.6	7.56		1.000	-.001	.115	-.217	-.193	-.187	.402*	.429**	.360*	.426**	.027	.396*
	O.S.C. EXP.	14.2	8.7	11.42		1.000	-.527*	-.162	-.267	-.329	-.545*	.644**	.550*	.126	.459*	.242	.386
	ALL SAMP.	14.2	4.6	9.00		1.000	-.094	.045	.017	-.125	-.121	.241**	.229**	-.121	.204**	.113	.184*
AROMA	WASH.	9	3	7.45			1.000	-.015	.393**	.261	.158	-.130	-.172	-.123	-.126	.249	-.159
	OREGON	9	4	7.34			1.000	-.033	.332**	.321**	.353**	.312**	.401**	.050	.406**	-.343**	.215
	CALIF.	9	5	7.47			1.000	.137	.257	.241	-.003	.198	.196	.198	.140	.258	.197
	O.S.C. EXP.	8	1	3.44			1.000	-.084	-.424	.809**	.633**	-.512*	-.364	-.027	-.341	-.469*	-.195
	ALL SAMP.	9	1	6.98			1.000	-.005	.356**	.511**	.336**	-.040	.008	.013	-.024	-.146	.084
AMOUNT OF LUPULIN	WASH.	9	4	6.86				1.000	.225	-.150	-.249	.449**	.440**	.184	.470**	.139	.329*
	OREGON	8	5	6.92				1.000	-.012	-.187	-.191	.295*	.278*	.125	.203	.270*	.195
	CALIF.	9	5	7.24				1.000	-.163	-.441**	-.395*	.551**	.533**	.532**	.463**	.397*	.539**
	O.S.C. EXP.	9	7	7.89				1.000	-.098	-.091	.232	.113	.145	.054	.109	-.169	.123
	ALL SAMP.	9	4	7.07				1.000	.031	-.194**	-.195**	.412**	.399**	.250**	.334**	.175*	.338**
COLOR AND COND. OF LUP.	WASH.	9	6	7.88					1.000	.431**	.074	-.153	-.193	-.167	-.106	.142	-.206
	OREGON	8	5	6.88					1.000	.071	.093	.065	.125	.050	.100	-.304*	.083
	CALIF.	9	6	7.15					1.000	-.041	-.102	-.225	-.218	-.223	-.215	-.201	-.228
	O.S.C. SAMP.	9	4	7.56					1.000	.281	-.072	-.607**	-.479*	-.598**	-.097	-.405	-.668**
	ALL SAMP.	9	4	7.16					1.000	.205**	.005	-.158*	-.135	-.153*	-.046	-.171*	-.161*
GENERAL APPEAR.	WASH.	9	6	8.16						1.000	.227	-.248	-.253	.099	-.402**	.002	-.080
	OREGON	8	5	6.97						1.000	-.009	.337**	.367**	.218	.221	-.145	.313**
	CALIF.	9	5	8.00						1.000	.405*	-.330	-.317	-.333	-.246	-.332	-.332
	O.S.C. EXP.	9	2	6.67						1.000	.597**	-.227	-.309	.187	-.342	-.313	.073
	ALL SAMP.	9	2	7.51						1.000	.339**	-.099	-.071	.053	-.139	-.186*	.001
COLOR (HUE)	WASH.	8.7	6.0	7.31							1.000	-.563**	-.566**	-.283*	-.522**	-.165	-.459**
	OREGON	8.0	5.6	7.02							1.000	+.027	.093	.056	.049	--.392**	.094
	CALIF.	9.2	4.8	7.58							1.000	-.522**	-.552**	-.488**	-.520**	-.139	-.518**
	O.S.C. EXP.	7.1	2.1	4.58							1.000	-.305	-.188	.245	-.338	-.384	.097
	ALL SAMP.	9.2	2.1	6.96							1.000	-.365**	-.344**	-.156*	-.323**	-.342**	-.248**

CORRELATION COEFFICIENTS NECESSARY FOR SIGNIFICANCE AT 5%* AND 1%** LEVELS

ORIGIN	NUMBER	.05*	.01**
WASH.	51	±.271	±.351
ORE.	64	±.243	±.316
CALIF.	34	±.330	±.425
O.S.C.	18	±.447	±.567
ALL	167	±.151	±.198

TABLE 9:

may also be of value in attempting to explain any apparent discrepancies between the correlation coefficients obtained with different lots of hops for any given pair of characters.

The factor broken cones was not included in the 1940 analysis. The table, therefore, includes the correlation coefficients between each of the eight physical factors measured and between each of the physical factors and each of the six chemical factors.

The reader is reminded that a correlation coefficient expresses the relative relationship between two characters. Both Table 9 on the 1940 data and Table 10 on the 1941 data should prove very valuable as a reference in regard to the nature of the relationship between factors.

Actually, it is not possible to present the information that is given in a form which will be more concise or explicit than that of the table of coefficents itself. A correlation coefficient is just as self-evident as is a temperature reading. However, a brief discussion of the more significant relationships existing between each of the physical factors and the remaining physical and chemical factors will be presented.

SEEDS

A negative correlation between seed content and color is found in every lot of hops except those from Oregon. It would seem logical that as hops become more mature they tend to have a higher seed content. Observations on some two thousand samples indicate that those samples with immature seeds have a lower percentage of seeds than samples with the same number of seeds but differing in that the seeds are plump and mature. Similarly, as the hops become more mature they go through the same color changes as is observed in most green plants. That is, the amount of green color decreases and the yellows become more predominant. Thus as seed content increases, color decreases. It is logical that both changes are associated with the development of maturity.

There is a strong negative correlation between seeds and the percentage of alpha resin. This holds true for all lots of hops. The explanation rests on two facts. The first of these is that alpha resin is transformed into beta resin as hops become overripe and throughout the entire cycle of resin deposition. Secondly, as the seed content increases it will decrease the relative proportion of all other components of the sample unless they are increased a comparable amount.

Support of this theory is provided by the fact that there is a positive relationship between seed content and beta resin. It is interesting to note that the relationship, while positive, is not significant in the case of the lots from California and Oregon State College which had the lowest and the highest seed content, respectively.

Inasmuch as seed content is negatively correlated with alpha resin, the similar correlation obtained for P.V. is not unexpected.

STEMS AND LEAVES

The character stems and leaves is not correlated very strongly with any of the factors except general appearance. The negative correlation here indicates that it is fairly important in influencing the evaluation which is given for this factor. Here again, it is observed that in the California and Oregon State College lots, which have the lowest average analysis, the correlation coefficients are not significant.

STRIGS

The lots from California and Oregon State College have positive correlation coefficients, significant at the 1% level, between the percentage of strigs and all the chemical factors except alpha and gamma or hard resin. The average analysis for strig content of these two lots is the lowest and highest, respectively, of all lots examined. This indicates that the effect of strig content is most apparent at the extremes.

There is some indication that strigs may have some importance in evaluating the chemical factors.

AROMA

In general, aroma is positively correlated with color and condition of lupulin, general appearance, and color. As is indicated by the average, the Oregon State College hops were characterized by their exceptionally poor aroma. One would expect that aroma should be positively correlated with all the chemical factors analyzed with the exception of hard resin. The Oregon and California hops show this trend, but, the samples from Washington and Oregon State College show negative correlations. This indicates that the relationship holds only in the upper level of aroma evaluation of the Oregon State College samples, and that the relationship fails with inferior aroma.

One factor to be considered in the 1940 data is that the methods were being developed when the data were being collected. It was necessary to develop an appreciation for differences in all of the physical factors measured. For this reason, it is believed that the 1941 data are more reliable than the 1940 data. Evidence for this contention is provided by the number of significant F values obtained with the 1941 data. The summary of these findings are in Table 15.

AMOUNT OF LUPULIN

Obviously, the negative correlation between amount of lupulin and general appearance is an indirect one. The fact that there is a strong positive correlation between color and general appearance indicates that those samples which had good color were given a high rating for general appearance, other factors being equal. If the theory, presented under the discussion on seeds, namely, that green color decreases with advancing maturity is accepted, the explanation for the negative correlation between amount of lupulin and general appearance becomes apparent. Thus, those samples which had the best green color were given the best evaluation for general appearance. The samples with the best green color were the most immature. The most immature samples had developed the least amount of lupulin. To complete the chain of thought, those samples given the best evaluation for general appearance had the smallest amount of lupulin.

The discussion in the preceding paragraph is borne out by the negative relationship obtaining between color and amount of lupulin.

The evaluation of the amount of lupulin has a strong positive correlation with the chemical factors. This indicates that the estimation of amount of lupulin is a reliable factor to use in predicting the resin content of hops. When the fact is considered that the method of estimating the amount of lupulin has been refined considerably since the data on the 1940 hops were collected, this factor assumes increased significance as a point to be considered in establishing a set of grades.

COLOR AND CONDITION OF LUPULIN

This factor presented considerable difficulty insofar as devising s suitable method of analysis was concerned.

In general, the relationship between it and the chemical factors appears to be a negative one. However, few of the coefficients obtained are significant. It appears from the trends indicated that the lupulin which was given the best score was found in the less mature hops. At present, this factor does not appear to be sufficiently standardized or reliable to have much merit.

GENERAL APPEARANCE

As was mentioned previously, general appearance has a strong positive correlation with color. As a result certain of the other factors considered have much the same relationship with general appearance as they have with color. Thus, for example, there is a positive relationship with alpha resin and a negative one with beta resin. The relationship between general appearance, color, maturity, and resin content would seem to be effective in explaining the observed correlation coefficients.

COLOR (HUE)

Certain apparent discrepancies appear here, but it is believed that there is a logical explanation for the relationships that obtain for the different lots.

It will be observed that, with the Oregon samples, the correlation coefficients are positive but of a very low magnitude. With few exceptions color is negatively correlated with the chemical factors analyzed in the other three lots and for the combined analysis.

While the averages do not indicate the fact very well, production practices in the three areas are considerably different. In California an effort is made to pick the hops while they are still quite green, so as to obtain approduct with a good green color, small cones and a general good appearance. In Oregon this practice is not followed. There is a tendency, in the opposite direction, of not getting the crop picked until part of it is considerably past the optimum stage of maturity. Thus, in the California hops there is a tendency to pick the hops too immature and as a result there is a negative correlation between color and the content of resins. With the Oregon hops this relationship tends to be reversed since the deviation from the optimum is in the direction of overripeness resulting in lower color value. With the Oregon hops the samples with the higher color values would be the ones which had been picked most nearly at the optimum stage of maturity. Resins are not fully developed in the immature hops which are picked in California. In Oregon, the alpha resin may be transformed to beta resin, but the resins are not lost in the period of color loss during the picking season.

1941 Data

A complete summary of the correlation analysis of five lots of 1941 hops and an analysis for the combined data of the three coast states is given in Table 10. The lots consist of 50 samples selected at random from the commercial samples submitted to the Oregon State College Hop Analytical Laboratory from each of the three states, the 128 samples from the Oregon State College

TABLE 10: A SUMMARY OF PHYSICAL AND CHEMICAL PROPERTIES OF SELECTED LOTS OF 1941 HOPS: WITH THE CORRELATION COEFFICIENTS BETWEEN PROPERTIES:

	VARIABLE	SEEDS	STEMS and LEAVES	STRIGS	AROMA	AM'T LUP.	COLOR and COND.	GEN. APPEAR.	COLOR (HUE)	BROKEN CONES	TOTAL RESIN	SOFT RESIN	ALPHA RESIN	BETA RESIN	HARD RESIN	P. V.
HIGH VARIATE	WASHINGTON	10.1	10.1	10.7	8	7.6	8	8	9.8	58.8	20.2	18.7	8.4	12.1	2.0	117.0
	OREGON	14.4	16.2	11.8	8	8.0	8	8	9.3	50.7	20.6	19.6	7.9	12.5	1.9	115.0
	CALIFORNIA	8.1	12.2	9.2	7	7.6	8	8	9.6	62.1	23.7	21.9	9.2	14.0	2.1	130.0
	3 COMBINED	14.4	16.2	11.8	8	8.0	8	8	9.8	62.1	23.7	21.9	9.2	14.0	2.1	130.0
	NEW YORK	7.0	18.6	9.1	7	8.0	7	7	8.1	47.5	18.9	17.2	7.1	10.8	1.8	104.6
	O.S.C. EXPR.	15.8	6.3	14.4	8	8.2	8	8	9.8	80.0	—	19.2	7.5	12.1	—	110.0
LOW VARIATE	WASHINGTON	0.2	0.9	5.6	3	3.8	5	5	7.2	10.0	12.7	11.7	3.6	5.6	0.7	68.0
	OREGON	0.2	1.9	4.3	2	3.3	5	5	5.1	7.0	12.7	12.0	3.6	7.2	0.7	71.0
	CALIFORNIA	0.0	1.2	5.3	2	4.5	5	5	6.1	10.7	11.2	10.0	5.0	4.8	1.0	65.0
	3 COMBINED	0.0	0.9	4.3	2	3.3	5	5	5.1	7.0	11.2	10.0	3.6	4.8	0.7	65.0
	NEW YORK	0.0	2.0	3.5	1	5.0	5	3	5.1	10.0	10.0	8.7	2.4	5.1	1.1	53.0
	O.S.C. EXPR.	3.7	0.1	3.0	3	2.5	5	5	6.6	17.5	—	12.2	3.1	8.1	—	62.0
AVERAGE OF ALL VARIATES	WASHINGTON	3.336	4.002	8.010	5.960	6.382	6.460	6.920	8.382	30.454	17.594	16.330	6.278	10.052	1.262	96.040
	OREGON	5.332	7.262	7.132	5.400	6.393	6.660	6.760	7.838	29.160	16.964	15.844	5.760	10.084	1.142	91.112
	CALIFORNIA	2.574	5.334	7.084	5.100	6.760	6.120	6.580	7.652	27.628	18.416	17.030	6.740	10.290	1.380	101.000
	3 COMBINED	3.747	5.533	7.409	5.487	6.511	6.413	6.753	7.957	29.081	17.658	16.401	6.259	10.142	1.261	96.053
	NEW YORK	2.641	9.023	6.065	4.647	6.294	6.235	5.176	7.453	27.294	14.423	12.935	4.259	8.682	1.472	71.523
	O.S.C. EXPR.	10.335	1.618	8.212	5.680	5.722	6.695	6.797	8.608	45.062	—	15.515	5.377	10.124	—	87.800
STANDARD DEVIATION	WASHINGTON	2.821	1.887	1.225	1.261	1.052	0.908	0.900	0.686	11.076	2.305	1.686	1.082	1.093	0.291	12.375
	OREGON	4.256	3.045	1.655	1.641	1.188	0.917	0.556	0.582	10.351	2.190	2.107	1.036	1.423	0.234	13.382
	CALIFORNIA	2.287	2.381	1.249	1.250	0.714	0.773	0.785	0.602	10.869	2.491	2.401	1.048	1.665	0.229	14.820
	3 COMBINED	3.208	2.467	1.381	1.386	0.998	0.863	0.775	0.621	10.697	2.316	2.071	1.048	1.404	0.251	13.472
	NEW YORK	2.581	4.927	1.750	1.694	1.105	0.664	1.075	0.692	11.821	2.435	2.265	1.227	1.586	0.221	14.596
	O.S.C. EXPER.	2.820	1.269	1.810	1.542	1.583	0.769	0.619	0.501	14.142	—	1.747	1.067	0.863	—	12.660

CORRELATION COEFFICIENTS

CHAR.	ORIGIN	HIGH	LOW	AVE.	SEEDS	STEMS and LEAVES	STRIGS	AROMA	AM'T LUP.	COLOR and COND.	GEN. APPEAR.	COLOR (HUE)	BROKEN CONES	TOTAL RESIN	SOFT RESIN	ALPHA RESIN	BETA RESIN	HARD RESIN	P. V.
SEEDS	WASH.	10.1	0.2	3.336	1.000	.296*	.155	-.054	-.396**	-.147	-.094	-.319*	-.096	-.303*	-.324*	-.509**	.004	-.483**	-.461**
	OREGON	14.4	0.2	5.332	1.000	-.230	.466**	.118	.170	.193	.017	.113	.165	.445**	.464**	.046	.642**	.028	.286*
	CALIF.	8.1	0.0	2.574	1.000	.332*	.230	.330*	.058	.431**	.062	-.210	.328*	.353*	.390**	.018	.551**	-.036	.210
	3 COMB.	14.4	0.0	3.747	1.000	.017	.347**	.116	-.023	.135	-.012	-.103	.119	.185*	.236**	-.128	.438**	-.207*	.056
	NEW YORK	7.0	0.0	2.641	1.000	-.087*	.462*	-.513	-.300	.023	-.273	-.202	.200	-.120	-.150	-.488*	.159	.149	-.345
	O.S.C.	15.8	3.7	10.335	1.000	.032	.181*	-.449**	-.576**	-.384**	-.220*	-.033	-.188*	—	-.249**	-.412**	-.005	—	-.354**
STEMS and LEAVES	WASH.	10.1	0.9	4.002	—	1.000	-.274*	-.190	-.178	-.102	-.284*	-.210	.023	-.236	-.311*	-.426**	-.058	-.090	-.371**
	OREGON	16.2	1.9	7.262	—	1.000	.049	.014	.147	.118	-.254	-.108	-.129	-.160	-.165	-.059	-.202	-.059	-.125
	CALIF.	12.2	1.2	5.334	—	1.000	.065	-.022	.082	.241	-.031	-.061	.007	-.102	-.077	-.210	.021	-.037	-.201
	3 COMB.	16.2	0.9	5.533	—	1.000	-.019	-.043	.042	.092	-.171*	-.118	-.042	-.156	-.160*	-.201*	-.086	-.126	-.204*
	NEW YORK	18.6	2.0	9.023	—	1.000	-.104	-.252	-.372	.002	.064	.149	.053	-.656**	-.644**	-.378	-.627**	-.618**	-.543*
	O.S.C.	6.3	0.1	1.618	—	1.000	-.184*	-.099	-.302**	-.219*	-.153	-.051	-.152	—	-.357**	-.396**	-.230**	—	-.388**

STRIGS	WASH.	10.7	5.6	8.010	1.000	.098	.251	-.059	-.014	-.078	-.024	.124	.164	.164	.090	.007	.146
	OREGON	11.8	4.3	7.132	1.000	.331*	.460**	.261	-.347*	-.120	-.065	.519**	.491**	.304*	.506**	.391**	.419**
	CALIF.	9.2	5.3	7.084	1.000	.243	.002	.211	.118	-.033	-.017	.109	.109	.093	.098	.006	.052
	3 COMB.	11.8	4.3	7.409	1.000	.246**	.294**	.148	-.069	-.079	-.038	.264**	.273**	.195*	.257**	.158	.220**
	NEW YORK	9.1	3.5	6.065	1.000	-.188	-.233	.202	-.279	-.060	.214	.191	.181	.090	.169	.212	.155
	O.S.C.	14.4	3.0	8.212	1.000	.242**	.277**	.168	.159	.034	.116	—	.288**	.017	.263**	—	.267**
AROMA	WASH.	8	3	5.960		1.000	.247	.498**	.429**	.441**	.069	.276*	.358**	.287*	.269	.134	.321*
	OREGON	8	2	5.400		1.000	.582**	.797**	-.004	-.166	.075	.478**	.484**	.529**	.331*	.088	.536**
	CALIF.	7	2	5.100		1.000	.334*	.389**	.189	-.240	.016	.524**	.524**	.404**	.501**	.033	.504**
	3 COMB.	8	2	5.487		1.000	.418**	.590**	.210*	.016	.055	.425**	.458**	.412**	.369**	.144	.460**
	NEW YORK	7	1	4.647		1.000	.426	.023	.105	-.223	-.127	.528*	.565*	.558*	.379	.087	.602**
	O.S.C.	8	3	5.680		1.000	.698**	.601**	.418**	-.117	.302**	—	.622**	.695**	.401**	—	.685**
AMOUNT of LUPULIN	WASH.	7.6	3.8	6.382			1.000	.276*	.074	.243	.092	.446**	.540**	.539**	.299*	.389**	.565**
	OREGON	8.0	3.3	6.393			1.000	.501**	-.024	-.415**	-.114	.759**	.748**	.636**	.645**	.294*	.714**
	CALIF.	7.6	4.5	6.760			1.000	.445**	.060	-.034	.131	.427**	.420**	.538**	.261	.050	.494**
	3 COMB.	8.0	3.3	6.511			1.000	.403**	-.022	-.067	.021	.542**	.564**	.565**	.409**	.342**	.586**
	NEW YORK	8.0	4.5	6.294			1.000	.411	-.204	-.479*	.077	.530*	.535*	.480*	.399	.371	.543*
	O.S.C.	8.2	2.5	5.722			1.000	.557**	.247**	-.172*	.381**	—	.719**	.814**	.458**	—	.786**
COLOR and CONDITION of LUPULIN	WASH.	8	5	6.460				1.000	.221	.282*	-.041	.271	.307*	.191	.284*	.376**	.262
	OREGON	8	5	6.660				1.000	-.003	-.212	.240	-.350*	.371**	.376**	.276*	-.085	.399**
	CALIF.	8	5	6.120				1.000	.186	.048	-.006	.294*	.318*	.125	.380**	-.014	.219
	3 COMB.	8	5	6.413				1.000	.147	.052	.065	.302**	.327**	.235**	.307**	.096	.293**
	NEW YORK	7	5	6.225				1.000	.026	-.177	-.053	.194	.177	.220	.082	.349	.211
	O.S.C.	8	5	6.695				1.000	.630**	-.135	.140	—	.579**	.604**	.424**	—	.600**
GENERAL APPEAR.	WASH.	8	5	6.920					1.000	.623**	-.435**	.026	.027	.122	-.079	.027	.055
	OREGON	8	5	6.760					1.000	.307*	.248	-.204	-.184	-.173	-.147	.173	.169
	CALIF.	8	5	6.580					1.000	.492**	-.300*	-.160	-.154	-.153	-.113	-.025	-.170
	3 COMB.	8	5	6.753					1.000	.502**	-.223*	-.095	-.097	-.044	-.106	-.084	-.085
	NEW YORK	7	3	5.176					1.000	.164	.333	-.310	-.298	-.169	-.298	-.316	-.250
	O.S.C.	8	5	6.797					1.000	.234**	.198*	—	.383**	.223**	.301**	—	.404**
COLOR (HUE)	WASH.	9.8	7.2	8.383						1.000	-.240	-.019	-.075	.092	-.207	.316*	.024
	OREGON	9.3	5.1	7.838						1.000	.090	-.128	-.113	-.124	-.076	-.156	-.118
	CALIF.	9.6	6.1	7.652						1.000	-.113	-.550**	-.563**	-.426**	-.544**	-.008	-.542**
	3 COMB.	9.8	5.1	7.957						1.000	-.099	-.233**	-.078	-.139	-.288**	.068	-.218**
	NEW YORK	8.1	5.1	7.453						1.000	-.238	-.263	-.276	-.082	-.332	-.074	-.187
	O.S.C.	9.8	6.6	8.608						1.000	.083	—	-.108	-.088	-.106	—	-.093
BROKEN CONES	WASH.	58.8	10.0	30.454							1.000	.127	.178	.121	.155	-.011	.174
	OREGON	50.7	7.0	29.160							1.000	-.170	-.139	-.209	-.054	-.326*	-.162
	CALIF.	62.1	10.7	27.628							1.000	.232	.246	.190	.235	-.012	.227
	3 COMB.	62.1	7.0	29.081							1.000	.076	.100	.040	.117	-.127	.086
	NEW YORK	47.5	10.0	27.294							1.000	-.224	-.222	-.433	.013	-.210	-.356
	O.S.C.	80.0	17.5	45.062							1.000	—	.255**	.301**	.162	—	.293**

H.R.F. 4-20-42

CORRELATION COEFFICIENTS NECESSARY FOR SIGNIFICANCE AT 5%* and 1%** LEVELS

ORIGIN	NUMBER	.05*	.01**
WASH.	50	±.274	±.355
ORE.	50	±.274	±.355
CALIF.	50	±.274	±.355
3COMB.	150	±.159	±.208
N.Y.	17	±.459	±.582
O.S.C.	128	±.172	±.225

experimental yard and 17 samples submitted from New York state by Professor J. D. Harlan. The data from the three coast states were combined by adding together the corrected sums of squares and sum products, thus, eliminating covariance between production regions. This made an analysis consisting of 150 samples. Altogether there are six sets of correlation coefficients involving a total of 295 samples.

The analysis is the same as that for the 1940 data with the exception of the fact that broken cones is an added factor. As a note of interest, it might be mentioned that there are 90 correlation coefficients calculated for each of the six groups of data.

Attention is called to the average for all variates. This is the average analysis for the samples analyzed for any one group. The results are in direct contradiction to claims made by Harlan (13, 14) that New York hops are superior to other United States hops.

A comparison of the averages for the different lots for the two years reveals that on the basis of the samples analyzed, no one area seems to produce a uniformly superior quality of hops. In 1940, the Oregon State College and Oregon hops had the highest P.V. In 1941, the California and Washington hops had the highest average P.V. The average content of leaves and stems shows an increase in 1941. This is a reflection of the difficulty of obtaining pickers in 1941 as compared with 1940. In both years, the lot with the highest average amount of lupulin also has the highest average P.V. The remainder of the relationships between the averages of the data from the various sources can be ascertained from observation of the data in the tables.

A discussion of the relationships between factors for the 1941 data follows. Again, the best picture of the relationships is obtained from observation of the table itself.

SEEDS

The data for Oregon and California appear to follow one trend and that for the lots of Washington, Oregon State College, and New York another. There is no apparent, logical explanation for this phenomenon.

One fact is indicated, and that is that further study with seeds will be necessary. At present, the analysis for seeds will be valuable insofar as it indicates the presence of extraneous material, the presence of which should be a penalty factor in a grade.

STEMS AND LEAVES

In general, stems and leaves are negatively correlated with resin content as would be expected since they are extraneous material which function as a diluent in decreasing the analysis of resins for a given sample. This relationship is fairly constant for all production areas.

STRIGS

The positive relationship between strigs and aroma and amount of lupulin indicates that the development of these three factors is parallel.

Although no attention has been attached to the strig content in the past, the relationships indicate that it may have some significance in estimating resin content.

AROMA

This analysis is particularly interesting. First of all, as was mentioned previously, it indicates that the accuracy of the method of estimating aroma was greatly increased over that obtained in the previous year's work. This is apparent from observation of the information on aroma presented in Table 15. It is believed that while aroma is dependent on sensory interpretation, it may still be evaluated with considerable accuracy by a trained observer. The fact that it has a strong positive correlation with the amount of lupulin and the color and

and condition of lupulin shows that these factors are parallel in their development and tend to lend support to each other in indicating the resin content.

The correlations between aroma and the chemical factors are significant at the 1% level for nearly all lots. This provides support for the practice of dealers considering aroma in purchasing hops in the past. However, the experiences of the past two years lead to the conclusion that some of the terminology used to describe aroma (flowery bouquet, etc.) are figments of overly-active imaginations.

Since aroma is so strongly correlated with amount of lupulin, it may well be that the regression coefficients will show that the correlation between aroma and the chemical factors is due to its relation to amount of lupulin.

AMOUNT OF LUPULIN

The analysis indicates that the amount of lupulin had a very large influence in determining the evaluation given the factor, color and condition of lupulin. Thus, when there was a large amount of lupulin present the appearance tended to be favorable and it was present in sufficient quantity to give a good sticky feeling. This would tend to discredit the validity of the estimation of color and condition to a certain extent.

The high positive correlation between amount of lupulin and the chemical factors show that this factor is susceptible of accurate application. It should be very useful in estimating the resin content of hops.

COLOR AND CONDITION OF LUPULIN

The fact that this factor is most strongly correlated with alpha resin indicates that it is of some value in indicating the maturity and age of the hops. From this standpoint it is a valuable factor to be considered. It is probable that the differences existing in hops with a wider range of age would be more pronounced and hence more easily detected than was the case with the hops of the lots considered.

GENERAL APPEARANCE

The correlation coefficient between general appearance and color is positive and significant, as in 1940.

With the exception of the Oregon State College data, this factor is negatively correlated with chemical factors. There is no good explanation why this disagreement between lots should exist.

As applied in these investigations, the factor general appearance is not very closely allied to chemical analysis.

This does not necessarily mean that it is of no importance. In certain cases it may be valuable in indicating special features that will be related to the effect of the hops on the beer. The presence of mold, not measured in aroma, would be a good example.

COLOR (HUE)

Color is negatively correlated to all the chemical factors analyzed. The relationship is not significant with any of the lots except California. However, the fact that the negative relationship is so constant shows that the practice of favoring a high natural green color is based on erroneous conclusions regarding hop quality. Again, as suggested previously, the more immature the hop the better the color and the lower the resin content. The fact that sulphuring is till practiced in some localities complicates the problem. It will be necessary to consider sulphured hops and unsulphured hops separately as far as the color factor is concerned.

BROKEN CONES

Hop dealers and brewers attach considerable significance to broken cones. This was indicated by the answers given to a questionaire regarding hop quality. One large hop producing organization included broken cones in the list of things considered in fixing the price of hops during the 1941 season. The theory is presented by dealers and brewers that hops with broken cones lose part of their lupulin and hence have a lower resin content than hops with less broken cones. All of these opinions and predjudices against broken cones are without factual basis. There has been no experimental evidence to support any of the conclusions regarding the extent of the importance of broken cones. In order to get some information regarding the significance of broken cones, it was included as a factor in the 1941 analysis.

The evidence obtained is somewhat contradictory. In the New York and Oregon data there is a negative correlation between broken cones and resin content. This would be evidence supporting the contention of brewers that broken cones lose part of their resin. However, the relationship is not statistically significant. This means that the relationship is not very constant and hence is unreliable. With the Washington, California, and Oregon State College data there is a positive correlation between broken cones and resin content. This indicates several things. First, it is not valid to assume that samples with the highest percentage of broken cones have the lowest resin content. It is probable that the more mature hops are broken by handling quite easily so that they have a higher percentage of broken cones than less mature hops. At the same time, it is plausible that, up to a certain point, they also tend to have the highest resin content. And finally, it appears that the resin is not lost to any appreciable extent because of breakage.

In regard to the Oregon State College data, reference to Table 5 shows that the Fuggles variety has the lowest analysis for broken cones and for the chemical factors, whereas the Late Clusters variety has the highest for both. This serves to explain the basis for the positive correlation more fully.

The results of the one year's study indicate that not too much importance should be attached to the factor broken cones.

COMPARISON AND DISCUSSION OF 1940 AND 1941 DATA

The nature of the relationship between physical and chemical factors for the two years is going to be discussed in detail in the section on the absolute relationships between physical and chemical properties. For this reason the following discussion will not be very detailed.

Most of the correlation coefficients for the two years of data are in fairly close agreement. As has been stated previously, the refinements and improvement in technique which were effective in obtaining the data on which the analysis for 1941 is based, make the 1941 data somewhat more reliable than that for 1940.

A comparison of Table 9 and Table 10 reveals that in 1941 higher correlations with other factors are obtained particularly with strigs, aroma, amount of lupulin, and color and condition of lupulin. It is probable that this is merely a reflection of the improved techniques in measuring the physical factors and is not due to a change in the relationship between the factors for the two years.

These analyses prove that certain definite and constant relationships do exist between various factors which are susceptible of fairly accurate analysis. It must be remembered that the reliability of the relationship is going to be dependent upon the accuracy of the measurements.

Since the correlation coefficient is a statistic expressing relative relationship only, it is of value only in indicating the existence or non-existence of relationship. For this reason, there is no particular point in attempting to discuss each correlation coefficient obtained separately. The figures are present in the tables and further interpretation can be placed on them as occasion arises for such need.

A SUMMARY OF THE ABSOLUTE RELATIONSHIPS BETWEEN PHYSICAL AND CHEMICAL PROPERTIES OF VARIOUS LOTS OF HOPS IN 1940 AND 1941

1940 Data

The regression coefficients, standard error of estimate, and multiple correlation coefficients between certain of they physical factors and the chemical factors are found in Table 11. In 1940, the regression coefficients were calculated for only those variables which were most significantly correlated with the chemical factors (as indicated by the correlation analysis). A study of the California data showed that using all eight of the physical variables did not account for much more of the variability of the chemical variables than using only the three or four most significantly correlated ones.

The regression coefficients, recorded in this study, express the absolute relationship, in terms of the chemical factor units, between the given physical factor and chemical factor. Thus, the regression coefficient expresses the change that will occur in the chemical factor for each unit change in the physical factor when all the other physical factors are held constant.

TABLE II: REGRESSION AND MULTIPLE CORRELATION COEFFICIENTS BETWEEN CHEMICAL AND PHYSICAL PROPERTIES OF SELECTED LOTS OF HOPS WITH THE CHEMICAL PROPERTIES AS THE DEPENDENT VARIABLES. 1940:

	GROUP OR LOT	VARIABLES USED	STANDARD ERROR OF ESTIMATE	REGRESSION COEFFICIENTS								MULTIPLE CORRELATION COEFFICIENTS
				SEEDS (X_1)	LEAVES (X_2)	STRIGS (X_3)	AROMA (X_4)	AMT. LUP. (X_5)	COND. LUP. (X_6)	GEN. APP. (X_7)	COLOR-HUE (X_8)	
Y_1 TOTAL RESIN	WASH.	$X_1 X_5 X_7 X_8$	1.1006	.0053				.4348		−.1379	−.9667	0.6412
	OREGON	$X_1 X_4 X_5 X_7$	0.9823	−.0145			0.3378	0.5510		0.4123		0.5394
	CALIF.	$X_3 X_5 X_8$	1.4581			.3496		.7408			−.6630	0.7066
	O. S. C.	$X_1 X_3 X_4 X_6$	0.5215	.1972		.2804	−.0030		−.5370			0.9364
	ALL SAMP.	$X_1 X_3 X_5 X_8$	1.2787	.0214		.1837		.5421			−.0507	0.4529
Y_2 TOTAL SOFT RESIN	WASH.	$X_1 X_5 X_7 X_8$	1.0623	.0191				.4033		−.1193	−.9296	0.6535
	OREGON	$X_1 X_4 X_5 X_7$	0.9267	−.0013			.4236	.5093		.4074		0.5850
	CALIF.	$X_3 X_5 X_8$	1.4000			.3702		.6601			−.7370	0.7226
	O. S. C.	$X_1 X_3 X_4 X_6$	0.9494	.1758		.2890	.0453		−.4631			0.7843
	ALL SAMP.	$X_1 X_3 X_5 X_8$	1.1989	.0355		.1697		.5138			−.4573	0.5243
Y_3 ALPHA RESIN	WASH.	$X_1 X_5 X_7 X_8$	0.6428	−.1048				.1229		−.0076	−.4962	0.6022
	OREGON	$X_1 X_4 X_5 X_7$	0.6242	−.1625			.3427	.3165		.1929		0.7473
	CALIF.	$X_3 X_5 X_8$	0.8699			.1729		.4120			−.3435	0.6632
	O.S.C.	$X_1 X_3 X_4 X_6$	0.6265	−.1017		.1089	.0917		−.3250			0.7667
	ALL SAMP.	$X_1 X_3 X_5 X_8$	0.7405	−.1198		−.0755		.2769			−.2131	0.5839
Y_4 BETA RESIN	WASH.	$X_1 X_5 X_7 X_8$	0.6024	.1210				.3029		−.0962	−.3909	0.8094
	OREGON	$X_1 X_4 X_5 X_7$	0.5851	.1601			.0706	.1958		.2220		0.8070
	CALIF.	$X_3 X_5 X_8$	0.7470			.1880		.2660			−.3609	0.6726
	O.S.C.	$X_1 X_3 X_4 X_6$	1.2884	.1185		.2567	−.0677		−.0177			0.5606
	ALL SAMP.	$X_1 X_3 X_5 X_8$	0.7342	.1419		.0930		.2571			−.2662	0.6938
Y_5 HARD RESIN	WASH.	$X_1 X_5 X_7 X_8$	0.2177	−.0125				.0256		−.0075	−.0681	0.2874
	OREGON	$X_1 X_4 X_5 X_7$	0.1889	−.0173			−.0535	.0873		−.0040		0.5271
	CALIF.	$X_3 X_5 X_8$	0.1649			−.0016		.0648			0.0032	0.3896
	O.S.C.	$X_1 X_3 X_4 X_6$	0.3370	.0240		−.0166	−.0460		−.0784			0.5678
	ALL SAMP.	$X_1 X_3 X_5 X_8$	0.2057	−.0151		.0128		.0337			−.1019	0.4424
Y_6 P. V.	WASH.	$X_1 X_5 X_7 X_8$	7.3840	−.6200				2.0790			−6.3430	0.5728
	OREGON	$X_1 X_4 X_5 X_7$	6.8660	−1.0750			3.7660	3.6810		2.6410		0.6406
	CALIF.	$X_3 X_5 X_8$	10.1270			2.3530		4.9070			−4.5580	0.6954
	O. S. C.	$X_1 X_3 X_4 X_6$	6.3240	−.1000		1.7220	.8400		−3.7150			0.7380
	ALL SAMP.	$X_1 X_3 X_5 X_8$	8.5380	−.6840		1.0780		3.4610			−2.5560	0.4902

TABLE 12: TABLE OF F VALUES: [INDICATING THE SIGNIFICANCE AND RELIABILITY OF CERTAIN PHYSICAL FACTORS IN ACCOUNTING FOR THE VARIABILITY OF CHEMICAL FACTORS IN SELECTED LOTS OF 1940 HOPS:]

CHEMICAL PROP.	SOURCE OF SAMPLES	SEEDS	STRIGS	AROMA	AMOUNT LUPULIN	COND. LUPULIN	GEN. APPEAR.	COLOR HUE	REGRESS. EQUAT.
TOTAL RESIN	WASHINGTON	.31			11.45**		1.77	20.41**	8.48**
	OREGON			6.21*	9.14**		9.31**		6.06**
	CALIFORNIA		7.19*		13.03**			.	9.97**
	O.S.C. EXPR.	27.40**	25.02**	.34		39.78**			23.14**
	ALL SAMPLES	1.63	9.30**		28.90**			1.99	10.45**
TOTAL SOFT RESIN	WASHINGTON	1.33			10.80**		1.63	20.55**	8.57**
	OREGON			11.03**	8.74**		11.02**		7.68**
	CALIFORNIA		8.66**		11.97**			12.16**	10.93**
	O.S.C. EXPR.	6.64*	6.85*	-1.14		8.84*			5.20**
	ALL SAMPLES	3.76	9.13**		29.67**			18.89**	15.36**
ALPHA RESIN	WASHINGTON	15.49**			2.15		.06	8.61**	6.55**
	OREGON	62.65		2.00	4.41*		5.60*		18.67**
	CALIFORNIA		5.05*		11.07**			7.44*	7.85**
	O.S.C. EXPR.	7.09*	.90	-.26		10.80**			4.64*
	ALL SAMPLES	56.42**	3.64		16.97**			6.77*	20.95**
BETA RESIN	WASHINGTON	45.05			19.75**		4.75*	18.18**	21.93**
	OREGON	93.47**		4.08*	5.37*		7.80**		27.68**
	CALIFORNIA		7.64**		7.34*			9.82**	8.26**
	O.S.C. EXPR.	2.24	2.80	.88		.03			1.49
	ALL SAMPLES	97.97**	8.58**		23.95**			19.92**	37.60**
HARD RESIN	WASHINGTON								
	OREGON	10.93**		5.74*	7.02*		.21		5.97**
	CALIFORNIA		-.01		5.47*			-.08	1.79
	O.S.C. EXPR.								
	ALL SAMPLES	9.74**	1.87		4.72*			23.20**	9.88**
P. V.	WASHINGTON	1.52			5.52*		.30	15.12**	5.62**
	OREGON	18.58**		7.49**	6.33*		8.67**		10.27**
	CALIFORNIA		6.77*		11.97**			9.38**	9.38**
	O.S.C. EXPR.	.18	3.93	1.55		13.01**			3.88*
	ALL SAMPLES	11.20**	6.38*		23.22**			10.45**	12.81**

TABLE OF F VALUES NECESSARY FOR SIGNIFICANCE:

0.05 LEVEL *

0.01 LEVEL **

SOURCE OF SAMPLES	INDIV. VARIABLES .05 LEVEL	INDIV. VARIABLES .01 LEVEL	REGRESS. EQUAT. .05 LEVEL	REGRESS. EQUAT. .01 LEVEL
WASHINGTON	4.05	7.22	2.58	3.77
OREGON	4.00	7.08	2.52	3.65
CALIFORNIA	4.17	7.56	2.92	4.51
O.S.C. SAMPLES	4.67	9.07	3.18	5.20
ALL SAMPLES	3.90	6.81	2.43	3.45

H.R.F. 4-19-42

The calculated F values, which serve as indices of the significance of the regression coefficients in accounting for the variation of any chemical factor are found in Table 12. (Note: Technically, it would be more correct to state that the F value reflects the significance of variations occurring in the physical factor in accounting for variations occurring in the chemical factor.) The F value for the Regression Equation is the index of the index of the significance of all the physical factors, included in the regression analysis, in accounting for the variations of the chemical factor for different samples of a given lot. It is thus a measure of the significance of the multiple correlation coefficient.

It should be pointed out at this time that in certain cases negative F values are obtained. This occurs when the regression coefficient obtained, in the analysis of a given lot, is of an opposite sign from the correlation coefficient obtained between the two factors in the analysis of simple correlation. This may happen when there is a spurious relationship between the two factors. That is, the relationship which is observed is an accidental one and is due to the fact that both the physical and chemical factor are related to a second physical factor. When this happens, the use of the physical factor under consideration does not contribute to the amount of the variation of the chemical factor accounted for by the remainder of the physical factors included in the regression equation.

The regression coefficient is a more reliable statistic for indicating the true relationship between two characters than is the correlation coefficient. This is because the regression coefficient measures the degree of relationship (positive or negative) between two characters after the influence of all other characters, measured, has been removed. In such cases as may be found where the regression coefficient does not agree in sign or magnitude with the correlation coefficient, the regression coefficient is the statistic that expresses the relationship between the given factors most correctly.

To summarize the discussion, it may be stated that the regression coefficients express the absolute change of the dependent variable (chemical factor), from the mean or average for that variable, which will occur for each unit variation from the mean for the independent variable (physical analysis factor), all other factors remaining constant. In other words, the regression equation to give an estimate of any given chemical factor. An example of such a regression equation is given in the section on the Methods of Statistical Analysis. Actual values will be substituted into such an equation at the end of this section to illustrate the method.

The use of the regression equations which are ultimately established will be facilitated by the construction of suitable tables. These tables will be based on deviations of each factor around the accepted population mean. In the table, products of the deviations about the mean times the regression coefficient will have been calculated. Thus, estimating the chemical factors would simply be a matter of making the required evaluations of the physical factors, finding the appropriate value in the tables for the various factors, summating the values obtained and adding the total to the accepted mean for the chemical factor under consideration.

Before beginning the discussion of the data itself, the method of obtaining certain of the chemical factors will be presented.

Total Resin = Alpha Resin + Beta Resin + Hard Resin.

Total Soft Resin = Alpha Resin + Beta Resin

$$\text{P. V.} = \left[\text{Alpha Resin} + \frac{\text{Beta Resin}}{3} \right] \times 10.$$

From the information just presented, it will readily be seen that total resin, total soft resin, and P.V. are all functions of alpha resin, beta resin, and hard resin.

The regression coefficient for total resin, for total soft resin, and for P.V. will thus also be functions of the regression coefficients obtained for alpha, beta, and hard resins, since the regression coefficient is an expression of absolute relationship. An approximation of the regression coefficient for total resin will be obtained by adding together the regression coefficients of alpha, beta, and hard resin. Thus, using the regression coefficients obtained for the variable seed with the Washington data, we will find total resin as follows:

$$\text{Total Resin } (.0053) = \text{Alpha resin } (-.1048) + \text{Beta Resin } (.1210) + \text{Hard Resin } (-.0125).$$

Using the figures above, it will be found that the regression coefficient would be .0037 in place of the calculated .0053. Similarly, total soft resin may be calculated as follows:

$$\text{Total soft resin } (.0191) = \text{Alpha Resin } (-.1048) + \text{Beta Resin } (.1210)$$

Using the figures given, the regression coefficient for total soft resin would be .0162 in place of the calculated .0191. P.V. may be calculated as follows:

$$\text{P.V. } (-.6200) = \left[\frac{\text{Alpha Resin } (-.1048) + \text{Beta Resin } (.1210)}{3} \right] \times 10$$

P.V. computed on this basis would be found to be -.6450 instead of the actual calculated P.V. of -.6200.

The previous examples have demonstrated that the regression coefficients obtained for total resin, total soft resin, and P.V. are functions of the regression coefficients obtained for alpha, beta, and hard resin. This being the case, the discussion of physical factors will be limited to their effect on the three independent chemical factors, alpha, beta, and hard resin.

SEEDS

The regression of alpha resin with seeds is negative for every lot. With beta resin, the reverse is true. It will be noted that the size of the regression effective for different lots does not vary appreciably. In every group, the regression is within .0400 units of the average obtained for all groups. Apparently, the effect of seeds is of equal importance for all groups.

The evidence seems to indicate quite conclusively that there is a parallelism between increase in seed content and the transformation of alpha resin into beta resin. Since beta resin is considered to be only one-third as potent as alpha resin in contributing to the preservative value of the hops, it would be concluded that it is undesirable to allow hops to reach their full maturity, as expressed in terms of the maximum seed content possible.

The negative regression of hard resin with seeds is due to the relative effect of their proportions on the hop sample as a whole. The hard resin content covers a small range of variation and contributes less than 2% to the total weight of the sample. When the seed content is increased 1% or more, it causes a relative decrease in the percentage of hard resin in the sample. In other words, seeds serve as a diluent. The effect is comparable to that which would be obtained by adding a quart of water to a quart of cream. The amount of butterfat present would be the same, but the percentage in terms of volume or total weight would have been decreased.

STRIGS

With the individual data from California and Oregon State College, strigs have a positive effect on both alpha and beta resin. Increases in all three factors are associated with advancing maturity. The regression of hard resin with strigs is negative and insignificant. The relationship between strigs and hard resin is comparable to that observed with seeds.

AROMA

Variations in the evaluation of aroma were not very significant in accounting for variations in the measurement of alpha resin, beta resin, or hard resin. However, the regression of alpha resin is positive and that with hard resin is negative. This shows that aroma indicates quality.

AMOUNT OF LUPULIN

There is a strong positive regression of all three chemical factors, under consideration, with the amount of lupulin. This is very encouraging. It proves that the estimation of the amount of lupulin is susceptible of accurate measurement (accuracy can be increased though), and will be very valuable in estimating the chemical factors.

COLOR AND CONDITION OF LUPULIN

All the chemical factors show a negative regression with the color and condition of lupulin. However, the amount of variation accounted for by the factor is significant only in the case of alpha resin. The explanation for this observed phenomenon rests on the fact that the best appearing and the stickiest lupulin occurred in hops which were still quite immature. The amount of all the resins increased after this theoretical stage of development but did not appear quite as desirable. Actually, the hops with the most resin did not have the best appearing resin. The factor cannot be considered as being very reliable as yet.

GENERAL APPEARANCE

The regressions for alpha and beta resin are negative with the Washington data and positive with the Oregon data. The F values are not significant for Washington and are significant for the Oregon data. The evaluation for this factor is at present unsatisfactory.

COLOR (HUE)

There is a negative regression between all chemical factors and color. This definitely proves that the practice of using high green color as a guide to high quality is wrong. The significant F values indicate further, that color, if interpreted properly, has definite value in adjudging quality. (The use of the regression coefficient makes it possible to interpret any factor properly.)

1941 Data

Regression coefficients were calculated for all nine of the physical factors in 1941. This was done in order to provide evidence of the significance or lack of significance of all factors. The standard error of estimate, the multiple correlation coefficient (R), and the multiple correlation coefficient ($\bar{R}$) are also calculated for each chemical factor with each lot. The summary of these statistics are included in Table 13. The F values which have been calculated for every factor are contained in Table 14.

The general discussion in the preceding section on the 1940 data is applicable to the 1941 analysis also.

SEEDS

The relationship obtained is the same as found in 1940. The regression of alpha and beta resin are negative and positive, respectively, with seed content. There is no explanation for the positive regression of alpha resin with seeds found with the Oregon State College data. The reasons for the observed regressions are the same as for the 1940 data.

STEMS AND LEAVES

It is significant that all chemical factors have a negative regression with stems and leaves. The explanation in all cases is that stems and leaves act as a

TABLE 13: A SUMMARY OF THE RELATIONSHIP BETWEEN PHYSICAL AND CHEMICAL PROPERTIES OF SELECTED LOTS OF HOPS WITH THE CHEMICAL PROPERTIES AS DEPENDENT VARIABLES

DEPENDENT VARIABLE	SOURCE of SAMPLES	REGRESSION COEFFICIENTS: SEEDS	LEAVES and STEMS	STRIGS	AROMA	AMOUNT of LUPULIN	C and C of LUPULIN	GENERAL APPEAR.	COLOR (HUE)	BROKEN CONES	STANDARD ERROR OF ESTIMATE	MULTIPLE CORR. COEFF. [R]	MULTIPLE CORR. COEFF. [R̄]
Y_1 TOTAL RESIN	WASHINGTON	-.1775	-.1466	-.0100	.4563	.7332	.2620	.1034	-1.2131	-.0008	2.0601	.5900	.4488
	OREGON	.1320	-.1660	.0376	.1229	1.3693	-.1317	-.4017	.6693	-.0294	1.1510	.8801	.8508
	CALIFORNIA	.2080	-.2416	-.0015	.4343	1.0696	.2225	-.0199	-1.8761	.0171	1.6896	.7903	.7349
	3 COMBINED	.1103	-.1905	-.0001	.3819	1.0252	.0240	-.2494	-.6556	-.0020	1.7771	.6686	.6414
	NEW YORK	-.0460	-.2124	.4083	.4638	.5779	.0420	-.2862	-.0602	-.0402	1.8673	.8618	.6418
	O.S.C.	—	—	—	—	—	—	—	—	—	—	—	—
Y_2 TOTAL SOFT RESIN	WASHINGTON	-.1268	-.1781	-.0523	.5010	.6967	.1519	.0371	-1.2202	-.0018	1.3217	.7057	.6206
	OREGON	.1439	-.1572	-.0245	.1122	1.3153	-.0573	-.4020	.6817	-.0253	1.1271	.8757	.8449
	CALIFORNIA	.2229	-.2186	-.0932	.3979	.9266	.3275	.0601	-1.9100	.0199	1.5947	.7999	.7475
	3 COMBINED	.1490	-.1674	-.0394	.4181	.9762	-.0216	-.5570	.1655	-.0005	1.5327	.6967	.6726
	NEW YORK	-.0547	-.1849	.4067	.4699	.5659	-.0665	-.2259	-.1116	-.0394	1.6948	.8689	.6634
	O.S.C.	.1831	-.1610	-.0490	.2070	.7303	.3057	.3300	.0984	-.0065	1.0743	.8055	.7887
Y_3 ALPHA RESIN	WASHINGTON	-.1474	-.1381	.0137	.2175	.3716	-.0518	.1147	-.5147	.0001	.8102	.7361	.6624
	OREGON	-.0306	-.0705	-.0013	.1446	.5022	.0411	-.2008	.3554	-.0167	.7812	.7319	.6567
	CALIFORNIA	-.0480	-.0997	.0768	.1429	.7428	-.0941	.0186	-.6815	.0114	.7577	.7573	.6910
	3 COMBINED	-.0542	-.0952	.0331	.1997	.4837	-.0673	-.0780	-.2045	.0007	.8017	.6711	.6443
	NEW YORK	-.1551	-.0067	.4920	.0753	.7908	-.4627	.3436	.0186	-.0694	.7986	.9025	.7591
	O.S.C.	.1173	-.1435	-.2318	.1855	.5604	.1048	.1981	.1920	-.0045	.4144	.9273	.9216
Y_4 BETA RESIN	WASHINGTON	.0186	-.0312	-.0612	.2642	.3290	.2084	.0229	-.7612	.0009	.9960	.5672	.4112
	OREGON	.1680	-.0890	-.0144	-.0384	.8156	-.0883	-.1971	.3344	-.0083	.7627	.8749	.8442
	CALIFORNIA	.2623	-.1184	-.1000	.2348	.1962	.4095	.0824	-1.2623	.0099	.8931	.874	.8440
	3 COMBINED	.1822	-.0805	-.0597	.1732	.4661	.0926	-.0984	-.5033	.0007	1.0580	.6827	.6571
	NEW YORK	.0985	-.1820	-.1223	.4027	-.2663	.4447	-.6128	-.1335	.0326	1.5019	.7795	.3211
	O.S.C.	.1347	-.0184	-.0181	.0454	.3006	.1770	.1900	.0098	-.0024	.7045	.6166	.5770
Y_5 HARD RESIN	WASHINGTON	-.0390	.0124	.0234	.0184	.0343	.1005	-.0709	.1008	-.0019	.2435	.6374	.5220
	OREGON	-.0081	-.0101	.0593	.0104	.0398	-.0692	.0264	-.0257	-.0049	.2122	.5724	.4199
	CALIFORNIA	-.0082	-.0194	.0204	.0601	.1528	-.0943	-.1145	.0747	-.0046	.1892	.6671	.5658
	3 COMBINED	-.0169	-.0159	.0219	.0114	.0730	.0006	-.0742	.0633	-.0034	.2248	.4990	.4481
	NEW YORK	.0054	-.0270	-.0005	-.0002	.0060	.1220	-.0558	.0449	-.0009	.2070	.7845	.3477
	O.S.C.	—	—	—	—	—	—	—	—	—	—	—	—
Y_6 P. V.	WASHINGTON	-1.4514	-1.4066	-.2205	2.9326	4.8272	.3956	.7284	-7.1584	.0195	2.8709	.7488	.6796
	OREGON	.3307	-.9826	-.0548	1.4660	7.5330	.0453	-2.3413	4.4863	-.1810	2.8841	.7880	.7319
	CALIFORNIA	.4725	-1.7752	-.0233	2.5977	8.3377	.3320	.2479	-11.6898	.1345	3.0170	.8134	.7652
	3 COMBINED	.1166	-1.3503	-.1988	2.7652	6.4839	-.4069	-1.4759	-3.7920	.0152	3.1115	.7062	.6830
	NEW YORK	-1.1283	-.6065	4.9046	2.0189	7.6949	-3.9174	1.9040	-.0834	-.6210	8.9599	.9139	.7894
	O.S.C. [H.R.F.]	.8750	1.5388	-.4476	1.9229	5.2264	1.2760	2.6046	.8034	-.0403	2.1969	.8485	.8359

TABLE 14: TABLE OF F VALUES: [INDICATING THE SIGNIFICANCE AND RELIABILITY OF CERTAIN PHYSICAL FACTORS IN ACCOUNTING FOR THE VARIABILITY OF CHEMICAL FACTORS IN SELECTED LOTS OF 1941 HOPS:]

CHEMICAL PROP.	SOURCE OF SAMPLES	SEEDS	LEAVES STEMS	STRIGS	AROMA	AMOUNT LUPULIN	CONDITION LUPULIN	GENERAL APPEAR.	COLOR [HUE]	BROKEN CONES	REGRESSION EQUATION
TOTAL RESIN	WASHINGTON	4.04	1.74	-0.04	4.22*	9.15**	1.72	0.06	0.43	-0.03	2.37*
	OREGON	20.22**	6.55*	2.61	7.80**	99.80**	-3.42	3.68	-4.02	4.18*	15.27**
	CALIFORNIA	7.18*	2.52	-0.01	12.16**	14.00**	2.16	0.11	26.59**	1.85	7.39**
	3 COMBINED	7.16**	7.99**	-0.00	24.58**	60.63**	0.68	1.96	10.36**	-0.18	12.57**
	NEW YORK	0.16	7.67*	1.52	4.64	3.78	0.06	1.06	0.12	1.19	2.24
TOTAL SOFT RESIN	WASHINGTON	5.84*	4.94*	-0.50	10.69**	18.71**	2.00	0.04	2.95	0.17	4.41**
	OREGON	23.11**	6.43*	-1.62	7.24*	94.97**	1.58	3.34	-3.63	2.96	14.58**
	CALIFORNIA	9.21**	1.85	-0.59	12.04**	12.72**	3.72	-0.34	29.97**	2.46	7.90**
	3 COMBINED	14.80**	8.69**	-1.95	34.91**	72.14**	-0.80	5.38*	-1.05	-0.06	14.67**
	NEW YORK	.27	7.40*	1.62	5.68*	4.22	-0.10	0.91	0.27	1.30	2.40
	O. S. C. EXPR.	-24.74**	14.02**	-4.91**	38.14**	159.78**	26.20**	15.04**	-1.02	-4.49*	24.22**
ALPHA RESIN	WASHINGTON	17.09**	8.96**	0.22	6.35*	17.02**	-0.73	1.02	-2.63	0.01	5.26**
	OREGON	-0.50	1.06	-0.06	10.45**	31.56**	1.18	1.61	-2.14	3.01	5.13**
	CALIFORNIA	-0.18	4.46*	0.80	6.45*	25.52**	-0.18	-0.20	15.66**	2.10	5.98**
	3 COMBINED	5.39*	11.47**	2.17	27.70**	66.33**	-3.32	0.63	4.30*	0.07	12.75**
	NEW YORK	6.01*	0.38	2.38	2.19	12.91**	-2.08	-1.92	-0.03	10.93*	3.42
	O. S. C. EXPR.	-107.58**	56.91**	-5.59*	156.99**	569.92**	38.46**	37.26**	-6.65*	-15.01**	80.52**
BETA RESIN	WASHINGTON	0.01	0.18	0.36	4.83*	5.59*	2.90	-0.09	5.82*	0.09	2.11
	OREGON	55.00**	6.55*	-1.45	-2.50	74.85**	-2.68	1.93	1.78	0.56	14.50**
	CALIFORNIA	33.83**	-0.62	-1.26	15.03**	3.74	12.30**	-0.74	42.26**	2.58	14.48**
	3 COMBINED	47.85**	3.2	-3.96*	16.56**	35.58**	4.58*	1.47	16.80**	0.16	13.58**
	NEW YORK	0.45	6.32*	-0.41	2.91	-1.32	0.27	2.21	0.35	0.06	1.20
	O. S. C. EXPR.	-0.42	1.08	-1.90	6.20*	48.06**	12.75**	7.75**	-0.11	-1.20	8.04**
HARD RESIN	WASHINGTON	12.28**	-0.49	0.09	-0.73	3.26	7.92**	-0.40	5.44*	0.05	3.04**
	OREGON	-0.24	0.46	9.77**	0.38	3.55	1.38	-0.64	0.60	4.24*	2.17*
	CALIFORNIA	1.56	3.91	0.36	5.70*	12.46**	2.32	5.20	-0.78	1.34	3.56**
	3 COMBINED	8.31**	3.68	3.54	1.68	20.13**	0.04	3.48	2.10	3.46	5.16**
	NEW YORK	0.16	6.79*	-0.02	0.00	0.21	2.33	1.56	-0.02	0.19	1.24
P. V.	WASHINGTON	13.89**	7.24**	-0.29	8.72**	21.12**	0.69	0.27	-0.87	0.28	5.67**
	OREGON	3.17	2.96	-0.30	10.16**	50.41**	0.13	1.73	-2.44	2.40	7.28**
	CALIFORNIA	1.81	6.78*	-0.12	13.04**	23.45**	0.45	-0.26	30.45**	2.64	8.69**
	3 COMBINED	0.43	14.26**	-1.25	36.52**	78.57**	-2.13	1.96	10.67**	0.29	15.48**
	NEW YORK	2.93	4.72	3.86	5.98*	13.42**	-1.60	1.48	0.03	7.60*	3.94*
	O. S. C. EXPR.	-29.06**	25.24**	-7.20**	63.66**	216.64**	19.56**	21.73**	-1.25	-5.56*	33.72**

TABLE OF F VALUES NECESSARY FOR SIGNIFICANCE

0.05 LEVEL *
0.01 LEVEL **

H.R.F. 4-20-42

SOURCE OF SAMPLES	INDIV. VARIABLES .05 LEVEL	INDIV. VARIABLES .01 LEVEL	REGRESS. EQUAT. .05 LEVEL	REGRESS. EQUAT. .01 LEVEL
WASHINGTON	4.08	7.31	2.12	2.88
OREGON	4.08	7.31	2.12	2.88
CALIFORNIA	4.08	7.31	2.12	2.88
3 COMBINED	3.91	6.81	1.94	2.53
NEW YORK	5.59	12.25	3.68	6.71
O. S. C. EXPR.	3.92	6.84	1.95	2.56

diluent. As such, the penalization for the presence of stems and leaves should be in direct proportion to the amount present.

STRIGS

The F values are not significant in most cases and many of them are negative. This tends to cast doubt on the value of strigs in estimating resin content. The findings do not agree with those of 1940. Further work will be necessary with this factor before it will be of any value.

AROMA

The regression between all chemical factors and aroma is positive. With the exception of beta resin in Oregon, and hard resin in New York. This shows that desirable aroma continues to increase as long as the resin content increases, and that the degree of development of the two is parallel. The significant F values show that aroma, as estimated in 1941, is closely related to resin content and hence will be of value in estimating the resin content. Furthermore, the evidence shows that the evaluations are quite accurate.

AMOUNT OF LUPULIN

Most of the F values obtained for this factor with the different sets of data are significant at the 1% level. The regression of all chemical factors with the amount of lupulin is positive. Each unit change in the estimation of the amount of lupulin is accompanied by a large change in the resin content. This factor is the most significant of all those considered, as far as accounting for variations of the chemical factors is concerned. Utilizing the method of analysis devised in obtaining the 1941 data, the estimation of the amount of lupulin is accurate and very valuable in estimating resin content. The fact that the regression coefficients for different groups are not equal in size, shows that the methods need some further standardization.

COLOR AND CONDITION OF LUPULIN

The 1941 data does not agree very well with that obtained in 1940. There is also disagreement between the data for different groups. The F values are generally not significant. The conclusion may be drawn that the evaluations for this factor are not very accurate. It is doubtful if it will be of value in estimating the amount of the various resins.

GENERAL APPEARANCE

The use of general appearance is significant only with the lot of samples from Oregon State College. The trends for all lots are contradictory and the F values obtained are not significant. It appears that general appearance, like color and condition of lupulin, is not uniform in its relation to the resin content of hops. It might be more correct to state that the method and estimation of the value of general appearance has not been developed in such a way that it reflects resin content. Such being the case, it is of limited value in indicating hop quality.

COLOR (HUE)

In those lots for which F values significant at the 1% level are obtained, the regression of the chemical factor with color is negative. This is in agreement with the findings of 1940. However, the regressions are positive for some lots and negative for others. The data indicate that positive regressions are obtained with those lots of hops in which some of the samples are picked after the optimum stage of maturity. Negative regressions are obtained with those lots of hops in which some of the samples are picked before the optimum stage of maturity is reached.

BROKEN CONES

The F values for the factor broken cones are not significant except for the New York and Oregon State College data with alpha resin and the Oregon data with hard resin. The remainder of the F values indicate that the influence of this factor on the resin content of hops is negligible. This conclusion is obvious from the small size of the regression coefficients themselves.

The evidence does not justify the use of broken cones in indicating quality of hops and its use as a factor in fixing the price of hops. In the event that broken cones indicate poor handling of the crop, there might be some occasion to penalize a high percentage of broken cones.

Nearly all the multiple correlation coefficients are significant at the 1% level. The analysis for the New York data is an exception. The calculation of $\bar{R}$, which is based in part on the variation of the dependent variable not accounted for by the independent variables, when compared with R will provide a measure of the constancy with which the relationships found in 1941 will exist in the future.

COMPARISON AND DISCUSSION OF 1940 AND 1941 DATA

A resume of the trends and nature of the absolute relationship between physical and chemical factors of the various lots of hops in 1940 and 1941 is given in Table 15. The table is constructed in such a way that it is possible to ascertain at a glance the comparison between the 1940 data and the 1941 data for each of the factors. The positive regression coefficients are indicated by a plus (+) sign, and the negative ones by a minus (-) sign. When the F value was significant at the 1% level, two +'s or two -'s are used and are entered in the column designated "S". When the F value was significant at the 5% level, one + or one - is used and is entered in the column designated "S". When the F value is not significant, a + or - is entered in the column designated "N". This table, of course, indicates only the sign and the nature of the relationships. Reference must be made to Tables 11 and 13 to find the actual regression coefficients.

Most of the relationships have been pointed out in previous discussion, but they will be summarized again.

The data for both years follow much the same trend with regard to the factor, seeds. This shows that the evaluation of seeds is a worthwhile feature in

TABLE 15: A TABLE SHOWING THE TRENDS AND NATURE OF THE ABSOLUTE RELATIONSHIP BETWEEN PHYSICAL AND CHEMICAL FACTORS OF VARIOUS LOTS OF HOPS IN 1940 AND 1941: [BASED ON TABLES 11 – 14 INCLUSIVE]

"S" INDICATES THE F VALUE WAS SIGNIFICANT: "N" INDICATES NON-SIGNIFICANT F VALUE:
"+" OR "−" UNDER "S" INDICATES SIGNIFICANCE AT 5% LEVEL: "++" OR "−−" UNDER "S" INDICATES SIGNIF. AT 1% LEVEL:

CHEMICAL FACTOR	SOURCE OF SAMPLES	SEEDS				STEMS LEAVES		STRIGS				AROMA				AMOUNT OF LUPULIN				COLOR AND COND. OF LUPULIN				GENERAL APPEARANCE				COLOR [HUE]				BROKEN CONES	
		1940		1941		1941		1940		1941		1940		1941		1940		1941		1940		1941		1940		1941		1940		1941		1941	
		S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N
TOTAL RESIN	WASH.		+		−		−				−			+		++		++					+		−		+	−−			−		−
	ORE.		−	++		−					+	+		++		++		++					−	++			−				+	−	
	CALIF.			+			−	+			−			++		++		++					+				−	−−		−−			+
	COMB.		+	++		−−		++			−			++		++		++					+				−		−	−−			−
	N. Y.				−	−					+				+				+				+				−				−		−
	O. S. C.	++						++					−							−−													
TOTAL SOFT RESIN	WASH.		+	−		−					−			++		++		++					+		−		+	−−			−		−
	ORE.		−	++		−					−	++		++		++		++					−	++	−		−				+		−
	CALIF.			++			−	++			−			++		++		++					+				+	−−		−−			+
	COMB.		+	++		−−		++			−			++		++		++					−			−		−−			+		−
	N. Y.				−	−					+			+					+				−				−				−		−
	O. S. C.	+		++		−−		+		−−			+	++				++		−		++				++					+	−	
ALPHA RESIN	WASH.	−−		−−		−−					+			+			+	++					−		−		+	−−			−		+
	ORE.	−−			−		−				−		+	++		+		++					+	+			−				+	−	
	CALIF.				−	−		+			+			+		++		++					−				+	−		−−			+
	COMB.			−		−−			+		+			++		++		++					−				−	−		−			+
	N. Y.			−			−				+				+			++					−				+				+	−	
	O. S. C.	−		++		−−			−	−			+	++				++		−−		++				++				+		−−	
BETA RESIN	WASH.	++			+		−				−			+		++		+					+	−			+	−−		−			+
	ORE.	++		++		−					−	+			−	+		++					−	++			−				+		−
	CALIF.			++			−	++			−			++		+			+			++					+	−−		−−			+
	COMB.	++		++			−	++		−				++		++		++				+					−	−−		−−			+
	N. Y.				+	−					−				+				−				+				−				−		+
	O. S. C.		+		+		−		+		−		−	+				++			−	++				++					+		−
HARD RESIN	WASH.		−	−−			+				+				−		+		+			++			−		−		−	+			−
	ORE.	−−			−		−			++		−			+	+			+				−		−		+				−	−	
	CALIF.				−		−		−		+			+		+		+					−			−		++			+		−
	COMB.	−−		−−			−		−		+				+	+		++					+				−		−		+		−
	N. Y.				+	−					−				−				+				+				−				+		−
	O. S. C.		+						+				−								−												
P. V.	WASH.		−	−−		−−					−			++		+		++					+		−		+	−−			−		+
	ORE.	−−			+		−				−	++		++		+		++					+	++			−				+		−
	CALIF.				+	−		+			−			++		++		++					+				+	−−		−−			+
	COMB.	−−			+	−−		+			−			++		++		++					−				+		−	−−			+
	N. Y.				−		−				+			+				++					−				+				−	−	
	O. S. C.		−	++		−−			+	−−			+	++				++		−−		++				++					+	−	

attempting to estimate resin content.

Regression coefficients are calculated for leaves and stems in 1941 only. The evidence is sufficiently conclusive so that it would be safe to state that there will always be a negative regression between the chemical factors and stems and leaves.

The 1940 and 1941 data for strigs do not agree. This would seem to indicate that the relationships that exist are accidental, and hence no significance can be attached to strigs in estimating the amount of resins in a sample.

The data for both years are in close agreement for aroma and for amount of lupulin. The F values obtained are highly significant. Both of these factors are important and may be used to advantage in estimating resin content. If the same degree or improved accuracy is used in estimating aroma and the amount of lupulin, it is probable that the relationship between them and the chemical factors will remain more or less constant.

The data for the two years with the color and condition of lupulin is contradictory. The evidence would indicate that the evaluation is not made in such a way as to reveal the relationship between amount of resin and color and condition of lupulin with a reliable degree of constancy. Until it becomes possible to achieve this, there will be no advantage in including it as a factor.

The variations occurring in the regression of the chemical factors with general appearance, with different lots analyzed, indicate that evaluations for this factor cannot be utilized in estimating resin content.

Color has been shown to have considerable importance as an indicator of resin content. However, differences of production practices in different production regions may necessitate that the hops from the various regions be evaluated separately, at least until the production practices have been standardized.

Broken cones has already been discussed under the discussion on the 1941 data. It is of no importance in accounting for variations in the resin content of hops.

On the basis of previous discussion, the factors which merit serious consideration in evaluating the resin content of hops are seeds, leaves and stems, aroma, amount of lupulin, and color. The other factors may have some significance in other respects, but it would be necessary to obtain evidence indicating this fact from further investigations.

The reader may not have observed the fact, but it should be noted that the calculation or estimation of any given chemical factor is based on calculations involving the averages for the chemical factor and for all the physical factors of the regression equation. The regression coefficient is multiplied times the deviation of the evaluation of a given factor from the accepted mean for that factor. Since the deviation of the evaluation for a given factor from the mean may be positive or negative, it naturally follows that the product of the regression coefficient times this deviation may be plus or minus also, depending on the sign of the regression coefficient, and the sign of the deviation.

In order to demonstrate the method of using the regression coefficients in the regression equation, one example will be worked out. Sample No. 3053 of the 1941 Washington data will be used as the example. Y_1 or total resin content will be estimated. The averages for Y_1 and each of the physical factors are obtained from Table 10. The regression coefficients for the Washington data are obtained from Table 13.

$\bar{Y}_1$ = 17.594

Se. Y_1 = 2.0601

The information which is presented in table form below are actually used in the regression equation, but it is believed that the table simplifies the procedure.

Sample No. 3053: 1941 Washington Hops:

Physical Analysis	Average	Deviation From The Average	Regress. Coeff.	Deviation X Regr.Coeff.
X_1 - 3.0	3.34	+2.96	-.1775	-.5254
X_2 - 3.5	4.00	-0.50	-.1466	.0733
X_3 - 8.3	8.01	+0.29	-.0100	-.0029
X_4 - 5.0	5.96	-0.96	.4563	-.4380
X_5 - 5.1	6.38	-1.28	.7332	-.5376
X_6 - 7.0	6.46	+0.54	.2620	.1415
X_7 - 7.0	6.92	+0.08	.1034	.0083
X_8 - 8.9	8.38	+0.52	-1.2131	-.6308
X_9 -34.0	30.45	+3.55	-.0008	-.0028

The summation of the products of regression coefficients X deviations of analysis of physical factors for Sample No. 3053 from mean for physical factors in 1941 Washington hops = -1.9144. Adding this quantity to the average total resin content of 1941 Washington hops (17.594) we find that our estimated total resin content for Sample No. 3053 will be 15.6796. The total resin content for this sample according to actual chemical analysis was 15.0. Thus our predicted analysis is well within the standard error of estimate (2.0601) estimating total resin content. The regression equation on which the above procedure is based is found on page 22 in the section on Methods of Statistical Analysis.

GENERAL DISCUSSION

The statistical analysis of the data including the calculation of correlation coefficients, multiple correlation coefficients, standard error of estimate, and regression coefficients has provided valuable information. However, this information has definite limitations which should be recognized.

The correlation coefficient, being a statistic of relative relationship between characters, gives only an indication of trends. Hence, it can be utilized only to show the nature of the relationship between factors. The regression coefficient, on the other hand, is a statistic of the absolute relationship between physical and chemical factors. Thus, if over a period of years a mean is established for the various physical and chemical factors, it will be possible to predict the chemical factors by utilizing the regression coefficients which have been derived. This information will be very valuable in the formulation of grades.

It must be recognized that the information which has been obtained has not completely solved the problem of measuring hop quality.

Brewmasters and brewers like to refer to "The science and art of brewing". Each brewmaster has certain preferences as to the best methods and the best materials for producing what he considers the "best" beer. Through the course of time, during which hops have been used in beer, predjudices regarding hop quality have arisen. Certain intangible factors of quality influence a brewmaster's choice of hops.

The epicurean conjures up visions of what he considers a good meal before he orders. It may include fine wines, delicate chops, and rich pastries; it may consist of a thick, juicy steak smothered with golden rings of onions; or it may be a golden-browned pheasant complete with all the trimmings. The factors involved in his particular choice at a given time are at best intangible and abstract. No two people would be in complete agreement as to what is the best type of meal. Selection of foods is based on cultivated tastes and predjudices. The protein, fats, carbohydrate, and vitamin content generally assume a secondary role in the factors considered when we select a meal. So it may be with the brewer in his selection of hops.

His choice is influenced by rules of thumb, predjudices, and numerous abstract and intangible factors. Some of his selection is based on his own experience. Sometimes he has factual basis for making a particular choice. In any event, it should be remembered that the

the art of brewing as it exists today is based on empirical experience accumulated over a period of several hundred years.

In the past, many brewers would use nothing but Czech hops or maybe Bohemian or Hungarian. Today, some want sulphured hops, some unsulphured. Some want green hops, some yellow, some think seeds are unimportant, some think they are detrimental to the brew.

This study has shown that the evaluations of general appearance and broken cones are not closely related to the resin content of hops. There is no evidence to show that they have any more effect on the beer itself. Yet, considerable importance is attached to both of these factors by brewmasters. It is easy to understand why they do attach significance to these two factors. The brewmaster wants to turn out the best product possible. To do this, he knows he must use the best ingredients that it is feasible to obtain. If he has a choice between a sample of hops that has mostly whole cones, and a good uniform appearance and color and another sample that may have some cones damaged from wind-whip and a considerable number of broken cones, he will automatically select the sample that has the "best eye appeal". He may not know how the two samples differ chemically or exactly what effect they will have on his brew, but his "instinct" tells him that one is better than the other. Whether or not this approach is a valid one is beside the point. The reaction to general appearance, color, and broken cones is a recognizable fact. This being the case, an effort must be made to either prove or disprove the validity of using them as factors which are important in determining the price paid for a lot of hops. If it can be shown that there is a relationship between these factors and the ultimate quality of brew in which the hops are used, the extent and importance of this relationship should be ascertained.

It is not suggested that an attempt should be made to standardize all brewing practices. However, many advantages might be gained by conducting tests and experiments from which it will be possible to ascertain, definitely and in terms of numerical values, the effect of each factor considered on the quality of beer itself.

Obviously, different brewers and consumers have varying opinions as to what constitutes quality in beer, but it should be possible to reach an agreement as to the nature of the effect of such factors as seeds, leaves and stems, general appearance, strigs, broken cones, etc. Tests to provide a factual basis for conclusions regarding the effect of various factors, real and intangible, could be devised. It is probable that procedures similar to those followed in the investigations, which have been discussed previously, would provide information of the sort desired.

After getting definite information on all the angles and questions regarding hops and hop quality, the task of putting the findings into practice still remains. It will be no easy job to overcome predjudices and customs should they prove erroneous. It must be recognized that it will not be possible to inaugurate a completely new basis for the sale and purchase of hops immediately. People cling to the old accepted way of doing things. They are naturally slow to adopt new practices, and do so only when thoroughly convinced that it will be to their benefit.

The work of the Oregon State College Hop Analytical Laboratory has laid a groundwork for the development of grades. At the present time, the hop trade has generally accepted the fact that seeds, and leaves and stems are two factors which influence hop quality. Many of the contracts on which hops are bought and sold carry provisions regulating the price that will be paid on the basis of seed and leaf and stem content. It may be necessary to educate growers and brewers in regard to the other features that constitute quality. This will be a gradual and more or less natural process. The features of a grading program cannot be forced on the trade. They must accept them voluntarily and be willing to abide by the standards set up. The grades must be such that they reflect quality. They must reward the production of superior quality hops. They must be of such a nature that they are easily interpreted, and susceptible of enforcement.

The analysis of the large numbers of samples included in this investigation has illustrated conclusively that results based on an analysis of only a few samples are subject to criticism. The wide range of quality in hops make it impossible to represent the hop crop of any state with only two or three samples as has been done by some workers in the past. Conclusions based on very small numbers of samples should be subjected to critical analysis before any faith is placed in them.

The samples, on which the analyses in this paper are based, cover a wide range of variation. Tables 9 and 10 show the high and low variate and the standard deviation of a single variate. These statistics are conclusive evidence that no attempt was made to restrict the investigations to any particular type of sample. The results are the more reliable because of this fact and are applicable to a wide range of quality of the hop crop.

SUMMARY

Quality of a sample of hops is defined as the degree to which the sample will fulfill the functions for which it is used in the production of beer.

Physical and chemical measurements are made on four different lots of hops consisting of a total of 167 samples in 1940. The same measurements are made on five different lots of hops consisting of a total of 295 samples in 1941. The data for the individual lots and certain of the data combined is submitted to an extensive analysis.

The factors included in the physical analysis are defined and the methods used in making the measurements are described. A brief resume' of the methods of statistical analysis is included. All the statistics are defined and an explanation of their utilization given.

Analysis of variance reveals that significant differences between varietal means and irrigation treatment means exist. There is also a significant interaction between varieties and irrigation treatments in certain cases. There are no significant differences between fertilizer treatment means.

The average analysis of seed content for Fuggles is significantly higher than that for Late Clusters.

The average analysis for Late Clusters is significantly higher for aroma, amount of lupulin, color and condition of lupulin, general appearance, percentage broken cones, total soft resin, alpha resin, beta resin and preservative value.

The average color analysis of samples from irrigated plots is significantly higher than that from non-irrigated plots. The amount of lupulin, and the color and condition of lupulin are significantly higher with the non-irrigated samples averages.

Significant interaction between varieties and irrigation treatments occurs with the amount of lupulin and the percentage of beta resin. With the amount of lupulin, there is a negative reaction of the Fuggles variety to irrigation. The Late Clusters variety shows a significant negative reaction to irrigation with beta resin.

Certain other trends with various factors are observed for the two varieties, for irrigation treatments, and also with fertilizer treatments but the differences are not statistically significant.

Valuable reference tables have been compiled. Statistics which have been calculated and compiled include (1) averages of all factors for all production areas, (2) averages of all factors for lots of hops under different cultural treatments, (3) correlation coefficients between factors for various lots of hops, (4) regression coefficients between physical and chemical factors for different lots of hops from major production areas, (5) multiple correlation coefficients between the several physical factors and each of the chemical factors, (6) standard error of estimate for the various chemical factors, and (7) the F values indicating the significance of each of the physical factors in accounting for variations of the chemical factor.

The correlation coefficients obtained indicate that certain highly significant and constant relationships exist between physical characters and between physical and chemical characters.

The regression coefficients and F values obtained show that some of the physical factors studied are susceptible of accurate measurement and will be of definite value in estimating the resin content of hops. Seed content, leaf and stem content, aroma, amount of lupulin, and color appear to be the factors which are most influential in affecting resin content of hops. Evaluations of color and condition of lupulin, and general appearance were not closely correlated to resin content. Evidence was presented to show that the significance attached to broken cones is based on invalid conclusions.

Percentage of broken cones does not affect the resin content.

The suggestion is made that work is necessary to determine the effect of the various factors on beer itself.

The findings apply to a wide range of quality in the hop crop. Indications are given that the methods of physical analysis have improved oonsiderably during the two years of the investigation and confidence may now be placed on their reliability.

BIBLIOGRAPHY

1. Alderton, G. Development of a Rapid Chemical Method For Hop Evaluation. A Thesis submitted to the Oregon State College. June, 1941.

2. Anonymous Hop Pests, Culture, and Handling Investigated. Special Agricultural Investigations. Oregon Sta. Circ. 130. 1938.

3. Breuer, W. Hops in General and Suggestions for the Improvement of American Hops. Jour. Amer. Soc. Brew. Tech. 2: 383-512. 1909-1910.

4. ________ The Practical Estimation and Valuation of Brewing Materials. Address and Discussion at Meeting of the Chicago Section of the American Society of Brewing Tech. Jour. Amer. Soc. Brew. Tech. 6: No. 6. 1915.

5. Bullis, D.E. The Colorimetric Method for Soft Resins in Hops. Indust. and Eng. Chem., Anal. Ed., 9: 267. 1937.

6. Coke, J.E. California Hop Production. Mimeographed Circ. 1933.

7. Doerell, E.G. Manuring of Hops with Periodical Applications of Nitrogen. Bodenk. Pflanzenernahr. 16: 90. 1939, Through Brit. Chem. Physiol. Ab. B. June, 1940.

8. Ezekiel, M. Methods of Correlation Analysis, New York, J. Wiley & Sons, Inc., London, Chapman & Hall, Limited. 1930.

9. Fortmann, H.R. and Huggins, W.H. A Discussion and Description of Certain Statistics and Some Suggested Procedures and Short-Cuts for Their Derivation. (Advance Copy -- Not Released for publication.) 1941.

10. Fore, R.E. Agronomic Studies with Hops in 1939 and 1940. (Progress Report - Hop Project). O.S.C. Circ. of Information 239. 1941.

11. Goulden, C.H. Methods of Statistical Analysis. New York, J. Wiley & Sons, Inc.; London, Chapman & Hall, Limited. 1939.

12. Haas, F.J. Effects of Sulphur on Curing Hops. West Coast Brewer 2, No. 5, 1937.

13. Harlan, J.D. Quality of Product Determines Demand for New York Hops. Farm Research Vol. II, No. 2, 1936.

14. ____________ Why New York Can Raise Quality Hops. Amer. Brewer 73: 13, 1940.

15. Hoerner, G.R. and Raback, F. Production of Hops. U.S.D.A. Farmers' Bull. 1842. 1940.

16. Horst, E.C. The Growing of Hops. Second Quarter Communications, 1936 M.B.A.A. Vol. 9, No. 2, 1936.

17. Kolbach, P., Rehberg, and Wilharm, G. The Influence of Maturity on the Brewing Properties of Hops. Wochschar. Brau. 55: 321, 1938.

18. Laufer, S. Factors Influencing Color of Beer and Ale. Amer. Brewer 74: 20-24. 1941.

19. McHugo, C.W. The preservative Power of Hops. Jour. Inst. Brewing 44: 294. 1938.

20. Monroe, C.G. and Hill, D.D. Methods for Determining the Percentage of Seeds, Strigs, Stems and Leaves in Commercial Hops. Jour. Amer. Soc. Agron. 31: 698-702, 1939.

21. Naatz, E.H. Does the Hard Resin of the Hop Impede the Solvency of the Soft Resin in Petroleum Ether and Beer Wort? Eighth Internat. Cong. of Applied Chem. XIV:111.

22. Pozen, M.A. Can Good Beers Be made with Domestic Hops? Brewery Age 7; No. 6:56, 1939.

23. Rabak, F. Aroma of Hops: A Study of the Volatile Oil with Relation to the Geographical Sources of the Hops. Jour. of Agric. Res. 2:115-119, 1914.

24. ____________ and Fore, R. E. Some Factors Influencing the Chemical Analysis of Hops. U.S.D.A. Mimeo, 1935.

25. __________ Some Studies of the Improvement of Quality of Domestic Hops. M.B.A.A. 10. First Quarter Comm. 1937.

26. __________ The Relation of Seeds, Leaves and Stems to the Quality of Hops and Malt Beverages. Materials Improv. Conn. M.B.A.A., 1937.

27. Rabak, F. Comparison of Domestic Seedless and Imported Hops. Address delivered before the Master Brewers' Association Convention at Buffalo 1938.

28. Salmon, E.S. Notes on a Visit to the Hop-Growing Districts of Bohemia Czechoslovakia. Jour. Inst. of Brew. XXXI, No. 10, 1925.

29. Shimwell, J.L. On the Relation between the Staining properties of Bacteria and Their Reaction towards Hop Antiseptic. Jour. Inst. Brew. 43:111, 1937.

30. Stockberger, W.W. The Necessity for New Standards of Hop Valuation. U.S.D.A. Bur. Pl. Ind. Circ. 33, 1909.

31. __________ Growing and Curing Hops. U.S.D.A. Farmers' Bulletin 304, 1928.

32. Tartar, H.V. and Pilkington, B. Hop Investigations Ore. Agric. College Bull. 114, 1913.

33. Wahl, R. Onion Beer Due to Sulphur. Brewery Age Dec. 1934.

34. Wallerstein, J.S. The Role of Hops in Brewing. The Hop Constituents and Their Significance in Beer Production. Wallerstein Laboratories Communications Vol. III, No. 8, 1940.