INSTITUTE OF BREWING RESEARCH SCHEME.

STATISTICAL STUDIES OF THE ANALYTICAL DATA ACCUMULATED IN THE COURSE OF THE BARLEY INVESTIGATIONS.

1.—THE PREDICTION OF EXTRACT.

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PART I.—GENERAL.

IT was suggested tentatively in an earlier Report (this *Journ.*, 1928, 101. *Roth. Mem.* Vol. 14) that in samples of any given variety of barley, the amount of nitrogen in the form of each of the separate proteins is regularly related, in the manner described in that communication, to the total nitrogen of the grain. It was further suggested that this regularity is uninfluenced by such conditions as soil, season and manuring. Subsequent studies have confirmed this relationship and made it clear that the amounts of the individual proteins can be calculated, for any given variety, from the total nitrogen content of the grain. In consequence the total nitrogen content is a good criterion of the "quality" of barley, in so far as this is affected by the amounts of each of these proteins, and in elucidating the part played by the nitrogen compounds in barley "quality," renewed confidence may be placed in the total nitrogen content. The present study is one result of the numerous applications of this principle.

It has often been suggested that the amount of nitrogen in barley is inversely related to the amount of starch in the grain or of extract obtainable from the malt, but the assertion has been denied or doubted and at present the relation is generally regarded as not strictly but only approximately true. It has also been asserted, and denied, that the larger the corns (*i.e.*, the smaller the proportion of husk and germ) the greater will be the amount of extract. The very large and valuable body of analytical data accumulated under the Institute of Brewing Research Scheme and published in the Reports on the "Influence of Soil, Season and Manuring on the Quality and Growth of Barley," 1924, *et seq.* has made possible a re-examination of these questions on a much sounder basis. Modern statistical methods have been employed which give not only the best estimate of the relationships which exist, but also a measure of their accuracy.

The results of this study of the relationship between the combined effects of nitrogen content and thousand corn weight of barley on the one hand, and on the other of the extract obtained from the corresponding malt are sufficiently encouraging to suggest that the estimation of nitrogen content and thousand corn weight should be of definite practical use in the valuation of barley and in the conduct of malting operations. In view of this it has been thought desirable to divide this paper into two distinct parts, to detail in the first some of the practical applications of the results and in the second, to describe the statistical methods by which these results were obtained and substantiated.

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In 1926 a series of 34 barleys grown from the same pure strain of Plumage-Archer seed was malted in lots of 7 to 25 quarters by Messrs. Gilstrap, Earp & Co., Ltd. The moisture, nitrogen content and thousand corn weight of the original unscreened barleys were determined as were the moisture and extract of the malts obtained from the same barleys after screening. The analytical results were published at the time (this *Journ.*, 1928, 321).

As a result of the statistical examination, described in detail later in this paper, of these analytical results, it was found that the extract of the malt (from screened barley) could be calculated in 68 per cent. of the samples to within 0·7 lb. per quarter from the following formula based on the nitrogen content and thousand corn weight of the original unscreened barley, the analytical data being calculated on dry matter.

$$E = 110{\cdot}1 - 11{\cdot}2 \times N + 0{\cdot}18 \times G$$

in which E = extract in brewers' pounds per quarter of *dry* malt.

N = nitrogen percentage on *dry* barley
G = weight of 1000 *dry* corns in grams.

This equation, which will be referred to as the "*extract equation*," was obviously calculated only to apply to the particular series of barleys and malts examined. These were all Plumage-Archer barleys of one strain, but they were grown in several different localities under varying conditions of soil, weather and manuring. The nitrogen percentage of the barleys ranged from 1·35 to 1·65 and the extracts of the malts from 97 to 102 lb. (calculated to dry malt). The malting loss also varied considerably. Thus the barleys represented a varied range with very different market valuations, but all of one variety. The agreement between the calculated results and those actually obtained in shown in the following table. (Table I).

TABLE I.

AGREEMENT BETWEEN EXTRACTS OBTAINED AND PREDICTED.

1926 *Bulk Malts.*

Extract, lb. per Quarter on Dry Malt.

Place.	Plot.	Calculated.	Found by analysis	found — calculated.
Dunbar	1	100·29	100·2	— 0·1
	2	100·29	99·5	— 0·8
Dunmow ..	3	99·02	99·7	+ 0·7
	4	100·16	100·4	+ 0·2
	5	100·50	100·2	— 0·3
	6	99·45	100·1	+ 0·7
Wellingore ..	11	100·32	100·3	0
	12	99·91	99·7	— 0·2
	13	99·91	100·3	+ 0·4
	14	101·54	100·9	— 0·6
Chiselborough ..	16	100·69	100·8	+ 0·1
	18	100·18	100·8	+ 0·6
	20	101·24	101·8	+ 0·6
	15	99·00	98·8	— 0·2
	17	99·67	100·9	+ 1·2
	19	100·29	101·1	+ 0·9
Sprowston ..	25	100·15	99·0	— 1·2
	26	99·76	99·7	— 0·1
	27	98·24	98·2	0
	28	97·89	97·0	— 0·9
Beverley ..	29	99·79	99·5	— 0·3
	30	99·82	99·1	— 0·7
	31	98·41	99·0	+ 0·6
	32	98·44	97·4	— 1·0
Longniddry ..	33	101·25	101·6	+ 0·4
	34	101·83	102·3	+ 0·5
	35	100·12	100·7	+ 0·6
	36	101·52	101·7	+ 0·2
Rothamsted ..	41	100·11	99·2	— 0·9
	42	99·22	98·1	— 1·1
	43	97·37	99·0	+ 1·6
	44	99·39	98·9	— 0·5
	45	99·14	99·1	0
	46	99·30	99·2	— 0·1

It remained to be decided whether the formula was applicable to other samples of English barley grown in different seasons under varying conditions and malted by different maltsters, since only in these circumstances would it be generally applicable to the purchase of barley and the control of malting operations.

The general applicability of the "extract equation" was tested by using the calculations for all other barleys malted in bulk for the Institute researches. These were not sufficient to yield satisfactory equations themselves, but the barleys were grown in different years and at different places and, in addition, they were malted by different maltsters so that they provide a very good test of the formula. The results are given in Table 2 (p. 423). In this table the extract calculated from the equation is compared with that obtained by analysis and also with the extract of the malt made experimentally by the "stocking" method. The different maltsters are referred to under letters and the barleys under the numbers used in the barley research reports. The only other variety of barley which it was possible to test with the data available was Spratt-Archer. The formula was found applicable to this variety if 0·5 lb. is added to the extract calculated for Plumage-Archer. That is for Spratt-Archer barley :—

$$E = 110{\cdot}6 - 11{\cdot}2 \times N. + 0{\cdot}180 \times G.$$

If any factor in the barleys themselves, apart from the nitrogen and the thousand corn weight, influenced the extracts, then it might be expected that "stocking"

TABLE 2.

COMPARISON OF CALCULATED EXTRACT WITH THAT OBTAINED FROM CORRESPONDING "STOCKING" AND BULK MALTS.

Maltsters	Barley	Extract of dry malt, lb. per quarter.				
		Stocking	Bulk	Calculated	Bulk—Calculated.	
		1928 SPRATT-ARCHER.				
A	401 B Longniddry	99·7	98·9	100·4	—1·5	—0·8
	402 B ,,	99.8	99·0	99·8	—0·8	
	403 B ,,	99.4	99·0	100·0	—1·0	
	404 B ,,	99·3	99·1	99·6	—0·5	
	405 B ,,	100·2	99·9	100·4	—0·5	
	406 B ,,	101·8	101·3	101·6	—0·3	
B	407/10 Wellingore	100·7	100·4	99·0	+1·4	+1.5
	408/11 ,,	100·9	101·6	100·7	+0·9	
	409/12 ,,	99·8	101·2	98·9	+2·3	
C	425/8 Fitzhead	101·0	100·5	100·5	0	+0·5
	426/9 ,,	101·9	100·9	100·3	+0·6	
	427/30 ,,	101·3	100·9	100·I	+0·8	
		1927 SPRATT-ARCHER.				
A	401/4B Longniddry	98·3	98·9	98·7	+0·2	+0·1
	402/5B ,,	100·1	100·8	100·8	0	
	403/6B ,,	98·6	100·1	99·9	+0·2	
B	414 B Kings Lynn	99·8	101·8	99·1	+2·7	+1·4
	413 B ,, ,,	100·8	101·5	101·0	+0·5	
	415 B ,, ,,	100·3	101·8	100·0	+1·8	
	416 B ,, ,,	101·1	101·5	101·1	+0·4	
	418 B Sprowston	100·7	102·0	101·0	+1·0	+0·0
	417 B ,,	101·8	103·9	101·9	—1·0	
C	427 B Fitzhead	100.3	100·8	100·5	+0·3	+0·2
	425 B ,,	100·3	100·9	100·8	+0·1	
	426 B ,,	100·3	100·6	100·3	+0·3	
		1926 SPRATT-ARCHER.				
D	7 Cawkwell	96·3	95·9	96·2	—0·3	+0·1
	8 ,,	99·1	97·6	98·6	+1·0	
	9 ,,	97·6	96·6	95·8	+0·8	
	10 ,,	98·6	99·0	98·1	+0·9	

TABLE 2 (Continued.)

Maltsters	Barley	Stocking	Bulk	Calculated	Bulk—Calculated.
		1924 Plumage-Archer			
D	Walcott, bulked	97·6	101·1	100·0	+1·1 } +0·4
	Wellingore ,,	98·9	101·0	101·3	—0·3
B	Orwell, bulked	98·6	101·5	100·5	+1·0 } +0·7
	Dunmow ,,	98·9	101·3	100·9	+0·4
		1922 Plumage-Archer.			
E	Barneyhill, bulked	98·5	99·8	101·6	—1·8
D	(1) Wellingore	96·2	96.9	97·7	—0·8
	(2) ,,	97·5	98.7	97·4	+1·3
	(3) ,,	97·7	98.7	97·7	+1·0 } +0.6
	(4) ,,	96·9	97.3	96·6	+0·7
	(5) ,,	98·3	99.0	98·4	+0·6
	(1) Walcott	95·3	98·5	97·6	+0·9
	(2) ,,	94·6	97·7	95·2	+2·5
	(3) ,,	94·5	98·0	96·2	+1·8 } +1.6
	(4) ,,	94·5	98·0	95·6	+2·4
	(5) ,,	95·1	97·9	97·4	+0·5

malting of the actual samples would give results in closer agreement with bulk malting than the predictions given by the equation. Actually the predictions give results which are very significantly closer to those obtained in the bulk maltings examined, as shown by the statistical test for significance known as the "Z" test. For an explanation of this see—R. A. Fisher, *Statistical Methods for Research Workers.* Section 41, p. 194. Third Edition 1930.

In 1927 the analyses used for the prediction were of the screened samples malted, but in the other years the analyses were of unscreened barley which was screened before malting. The lack of screening effect is explained later (pages 425 and 431).

Variations in soil and season similarly appear to have no marked influence on the accuracy of the results, as the barleys referred to in Table 2 were grown under different conditions from those of the 1926 series on which the equation was based.

The test of the equation provided by these results is very stringent and suffers from several disadvantages in comparison with its practical application. For instance the Walcott barleys of 1922 were so unsatisfactory that they would never have been malted commercially and consequently the agreements here are bad.

The main source of the differences between prediction and analysis is variation in malting conditions as shown by the results obtained by different maltsters. For each individual firm these differences are fairly constant from year to year. It will be seen for instance that maltster A obtains from 1 to 2 lb. less extract than B. Maltsters C and D obtain results which are close to the predicted but B's are consistently high.

It is thus clear that the equation as it stands will give a relative figure for the extract from barleys malted by any given maltster. Moreover the equation can be adjusted to give figures suited to any given malting conditions. Thus with maltster B's results an average correction of +1·1 lb. can be made. The predictions are then as close as for the other maltsters. See Table 3.

TABLE 3.

PREDICTIONS TO SUIT MALTSTER B.

Year	1928			1927			
Barley	407/10	408/11	409/12	414B	413B	415B	416B
Differences between analysis and calculation ..	+0·3	—0·2	+1·2	+1·6	—0·6	+0·7	—0·7

Year	1927		1924	
Barley	418B	417B	Orwell	Dunmow
Differences.	—0·1	+1·0	—0·1	—0·7

The results in Table 2 (p. 424) are not numerous enough for sound conclusions, but they suggest that when the "extract equation" is used for any Plumage-Archer or, with the appropriate alteration, for any Spratt-Archer barley malted by any maltster the standard error of the prediction will be ± 1·1 lb. This implies nothing about the accuracy of the agreement in any given case, but it does imply that 68·5 per cent. of the predictions will be within 1·1 lb. of the results actually obtained, while 95·5 per cent. of the predictions will be within 2·2 lb. of those obtained. Probably, when adjusted for any given maltster, the predictions will have a standard error of about ±0·8 lb., *i.e.*, 68·5 per cent. of the predictions will be within 0·8 lb. and 95·5 per cent. within 1·6 lb. The definition of the term "standard error" implies that 68·5 per cent. of the results will fall within the figure given, and 95·5 per cent. within twice that figure.

All that is necessary for any maltster to do is to find from a number of tests with either Plumage-Archer or Spratt-Archer barley, the average amount by which his predicted and obtained results differ and adjust the constant of the equation (110·1 or 110·6) by a corresponding amount, *e.g.*, with maltster B (110·1 + 1·1) the equation becomes for Plumage-Archer barley.

$$E = 111{\cdot}2 - 11{\cdot}2 \times N + 0{\cdot}18 \times G.$$

In the second part of this paper it is shown that the nitrogen factor varies with malting conditions but for ordinary conditions the figure given (11·2) is probably sufficiently accurate.

Effect of Screening.—It will have been noticed that unscreened barley was used in most cases for the prediction of the extract and this has been compared with the results obtained with malt made from the corresponding screened barley. There is a tradition that screening increases the extract obtained. This will be so of course if stones, half corns and weed seeds are removed, and may be true also if smaller grain of a different variety is removed from a mixed sample, but is not true otherwise at least for unmixed English barleys. The reason for this is discussed in the second part of the paper. It will be sufficient here to give a table of all the Institute comparison maltings of screened and unscreened samples, which, indicates that screening *lowers* the extract—see Table 4. This lowering is on the average 0·4 lb. and the value is clearly significant (by a Z test).

TABLE 4.

EFFECT ON EXTRACT OF SCREENING BARLEY.
(Comparison Stocking Maltings).

Barley.	Extract on dry malt lb. per quarter.		Difference= Effect of Screening.
	Unscreened	Screened	
1927			
401/4	98·9	98·3	—0·6
402/5	100·4	100·1	—0·3
403/6	98·6	98·6	0
427	100·8	100·3	—0·5
425	100·7	100·3	—0·4
426	100·6	100·3	—0·3
1928			
401	101·2	99·7	—1·5
402	100·1	99·8	—0·3
403	100·4	99·4	—1·0
404	100·2	99·3	—0·9
405	101·8	100·2	—1·6
406	102·0	101·8	—0·2
407/10	100·2	100·7	+0·5
408/11	101·6	100·9	—0·7
409/12	100·2	99·8	—0·4
425/8	101.1	101·0	—0·1
426/9	101.3	101·9	+0·6
427/30	101.1	101·3	+0·2

Effect of Malting Conditions.—It is possible by varying the malting conditions, for example, by over or under modification to alter the extract obtained from any given barley. In consequence when an equation for average conditions for any one variety has been obtained by a maltster, its use will enable him to detect deviations from his usual procedure which may have occurred. It is therefore suggested on the basis of these results that *this formula will be sufficiently accurate as a control of malting operations and for the prediction of extract for valuation purposes.*

No attempt has been made so far to derive an equation for use with foreign barley, or for any of the varieties grown in this country, other than Plumage-Archer or Spratt-Archer. The method proposed should however be equally applicable to all barleys and the appropriate equations could be calculated when the necessary data are available.

Notes on Use of Equation.

In the application of the method there are several practical points which must be borne in mind.

(1) The most important is that the sampling for analysis should be very carefully done *i.e.* small samples should be taken all over the bulk (even from screened barley or malt) and well mixed to give the sample for analysis. Otherwise sampling errors will cause a great increase in the "standard error" of the results for which the equation will be wrongly blamed.

(2) It is sufficient to analyse the unscreened barley, but laboratory screening of the sample would be preferable and would have the incidental advantage of giving an estimate of the amount of "tailings."

(3) The equation does not apply to samples which do not germinate well.

(4) The equations given should be used only for Plumage-Archer and Spratt-Archer barleys.

(5) It must be remembered that the formula gives the amount of extract on *dry* malt, not on sample. Similarly, the nitrogen percentage and thousand corn weight used in the calculation are those of *dry* barley.

It is suggested that the following laboratory estimations are made. (1) (optional) percentage of tailings; (2) moisture percentage; (3) nitrogen percentage; (4) thousand corn weight.

Attempts are being made in this laboratory to find means of speeding up the required estimations so that it may be possible to complete them within one to two hours.

Application.—An actual case is given as an example of the application of the "Extract equation" to the control of malting operations. The details were kindly supplied by a firm of maltsters and refer to a carefully selected range of Plumage-Archer barleys which were bulked to cover a large contract in which extract was an important factor. A series of steepings from this bulk had consistently given extracts of over 100 lb. on dry malt, when a particular floor fell to 99 lb. Hand examination of the barley failed to detect any reason for the lower extract, but analysis and calculation from the "Extract equation" immediately indicated that no fault was to be found with the malting operations and that the lower extract was all that was to be expected from the barley steeped. The details are given in Table 5. This particular maltster found it necessary to subtract 1·5 from the result given by the "Extract equation" to meet his conditions and the formula actually used was :

$$E = 108{\cdot}6 - 11{\cdot}2 \times N + 0{\cdot}18 \times G.$$

TABLE 5.

APPLICATION OF "EXTRACT" EQUATION.

Steeping	N. percent. on dry	1000 corn wt. of dry barley		Extract, lb. on dry malt.	
				Calculated	Analysis
1	1.304	43.29	42.0 for calcn.	101.6	100.4
2	1.300	42.16		101.6	101.6
3	1.247	43.60		102.2	100.5
4	1.545	43.60		98.9	99.1

PART II.—STATISTICAL EXAMINATION.

PREVIOUS RESEARCHES.

The opinions of previous workers on the relation between nitrogen content and extract are given by H. F. E. Hulton in Section IX. of his Report on Nitrogenous Matter in Brewing (this *Journ.*, 1922, 103-9) and need not be repeated here. Summarising, Hulton states that out of twenty-five authors who have examined the relation between nitrogen content and extract, thirteen believe that there is a definite inverse relation, nine are doubtful, and three deny that any such relation exists.

Fewer studies have been made of the possible effect of thousand corn weight on extract yield and it would appear that opinions are both for and against the existence of such a relation. Since Hulton's Report was written Scharnagel (*Z. ges. Brauw.*, 1927, **50**, 185) has claimed that there is no relation between extract and thousand corn weight. These conflicting views are due to the lack of statistical treatment, scantiness of the data examined, to the grouping together of different varieties, and probably to differences in modification of the different malts.

Several other methods of estimation of *relative* extract yields have been proposed. The one apparently in use in Sweden and Germany is to estimate the starch or extract content of the barley. This is a laborious operation and it is necessary to estimate the nitrogen content as well, owing to the effect of this on malting loss. Hastie (this *Journ.*, 1926, 343) recommends the valuation of barley for distillers' malt by the estimation of the starch content and germinative capacity However, he gives no quantitative relation, and as pointed out above it is necessary to estimate also the nitrogen content. The author is in agreement with Hastie when he points out how economically unsound it is to buy barley or malt on its appearance alone without the assistance of an objective measure of value, such as that afforded by some method of extract prediction.

STATISTICAL STUDY OF THE INSTITUTE DATA.

A preliminary empirical study suggested that the relation of nitrogen content and thousand corn weight of barleys to the extracts of the resulting malts was close enough to be of practical value. The data were then examined by appropriate statistical methods, since, when using sufficient suitable data, statistical methods can give, to a question such as the present one, an answer which is independent of personal bias. The method used is given by R. A. Fisher in "*Statistical Methods for Research Workers*," Section 29, p.132 of Third Edition, 1930.

The statistical calculations yield a *regression equation*, that is an equation such as will give the best agreement possible between the observed and calculated results. For instance, in the regression equation already dealt with ($E = 110{\cdot}1 - 11{\cdot}2 \times N + 0{\cdot}18 \times G$) no other set of values will give as close an agreement between the extracts calculated and those actually obtained. This applies, of course, only to the set of figures and variants used in the calculations.

In Table 1 (p. 422) the agreement between the calculated and the observed extract values is shown. The standard error derived from these figures by statistical methods is 0·7 lb. and this implies that 68·5 per cent. of the calculated values will be within $\pm 0{\cdot}7$ lb. of the observed, and 95·5 per cent. will be within $\pm 1{\cdot}4$ (*i.e.* $2 \times 0{\cdot}7$) lb. The remaining 4·5 per cent. will be outside this range.

The accuracy of the individual factors in the equation is measured in a similar manner. For instance, in the "extract equation" the standard error of the nitrogen factor is $\pm 1{\cdot}30$, *i.e.*, the value lies between 12·5 ($11{\cdot}2 + 1{\cdot}3$) and 9·9 ($11{\cdot}2 - 1{\cdot}3$) with a probability of 68·5 chances out of 100. That is, the fact that the figure of exactly 11·2 gives the best fit is the result of calculation from the available data only, and the variation in the agreements is such that the chances are 68·5 out of 100 that the true value lies between 12·5 and 9·9. Since the value of 11·2 is much more than twice its standard error (1·3) it is exceedingly improbable that the relation obtained is due to pure chance. In other words, the figures demonstrate that there is a really significant inverse relation between the nitrogen content of these particular barleys and the extracts of their malts.

Similarly the equation shows a direct relation between the thousand corn weight and the extract. The factor is here $0·18 \pm 0·07$. Since 0·18 is more than twice the standard error it is very unlikely also that this relation is due to chance. When the number of cases studied is less than 50 the probabilities are somewhat smaller than those given.

"Stocking" Results.

Most of the Institute data available applied only to barleys grown in experiments and malted in "stocking." As the quality of these barleys varied widely from "grinding barley" to high class malting barley, and as they were grown under such varying soil conditions over a number of years and the modification arrived at varied somewhat from year to year, they appeared to offer the necessary material on which to form an idea of the *maximum* error involved in the prediction of extract from an equation. This analytical data has consequently been examined in the same way as the 1926 set of bulk malted barleys and has been found to supply further confirmation of the value and reliability of the method. This examination has in addition furnished examples which show that it is possible to deduce from the analytical data, conclusions as to the degree of modification during malting.

Regression equations were calculated for each year of the Institute results, and these together with their standard errors are given in Table 6. The data used in calculating these equations are given in the "Reports on the Influence of Soil, Season and Manuring on the Quality and Growth of Barley," H. M. Lancaster and H. Lloyd Hind (this *Journ.* 1924, *et seq.*)

These figures demonstrate that there is in every case a fairly constant and clearly significant inverse relation between the nitrogen content of the barley and the extract of the resulting malt. This, therefore, supplies a definite and final answer so that *it can now be definitely stated that there is an inverse relation between nitrogen content and extract for one variety of barley.*

TABLE 6.

Regression Equations.

	Year.	Variety.	Method of Malting.	No. of cases.	Equation.	Standard Error.	S.E. of N. Factor.	S.E. of G Factor.
1	1922	Plumage-Archer	Stocking	89	$E = 108·43–8·977 \times N + 0·0807 \times G$	1·512	0·998	0·0490
2	1923	Plumage-Archer	Stocking	87	$E = 101·78–6·819 \times N + 0·2051 \times G$	1·921	1·082	0·0669
3	1924	Plumage-Archer	Stocking	81	$E = 104·34–5·850 \times N + 0·07086 \times G$	0·755	0·750	0·0432
4	1925	Plumage-Archer	Stocking	92	$E = 101·78–12·01 \times N + 0·3587 \times G$	2·138	0·836	0·0551
5	1925	Plumage-Archer N.I.A.B.	Stocking	24	$E = 109·13–11·45 \times N + 0·143 \times G$	1·50	2·26	0·0931
6	1926	Plumage-Archer	Stocking	91	$E = 104·23–8·490 \times N + 0·2133 \times G$	0·662	0·626	0·0263
7	1926	Plumage-Archer N.I.A.B.	Stocking	38	$E = 101·55–7·006 \times N + 0·1867 \times G$	0·726	1·089	0·0599
8	1927	Spratt-Archer	Stocking	78	$E = 109·04–10·42 \times N + 0·1798 \times G$	0·958	1·098	0·0464
9	1928	Spratt-Archer	Stocking	50	$E = 108·87–11·61 \times N + 0·2552 \times G$	0·759	0·469	0·0434
10	1926	Plumage-Archer	Bulk	34	$E = 110·12–11·20 \times N + 0·1799 \times G$	0·682	1·30	0·0704

Where E = extract in brewer's pounds per quarter (336 lb.) of dry malt.
N = nitrogen percentage on dry barley.
G = weight of 1,000 dry corns in grms.

Furthermore there is in each equation a direct relation between the extract and the thousand corn weight of barley; values ranging from about 0·15 to 0·25, in the units employed, apply in most cases. In three out of the ten equations this factor fails to attain significance. In one of these (No. 5) the failure is probably due to the small number of samples available. In the other two exceptional cases (Nos. 1 & 3) the thousand corn weights differ from those of other years in that a proportion are heavier than 42 grms. A study of the residual differences (*i.e.*, of differences between observed and predicted extracts) suggests that above this figure the increase of extract with size of grain does not continue to be as large, so that in these cases the data could be better fitted by adding a squared term to the equation:

$$E = a - b\,N + c\,G - d\,(G)^2$$

but this added complication will not be further considered in this paper. Allowance can be made for it in the "extract equation" by taking as 42 grms., all thousand corn weights above this value. Taking these various considerations into account it can be said on the basis of these results that it is beyond doubt that *the amount of extract available from the malt increases with increase in weight of the original barley grains* (at least up to a value of about 42 grms. per thousand corns).

The relation between nitrogen content and extract appears, from a study of residual differences, to be rectilinear. The factor is, however, larger than would be expected if it were due simply to the replacement of starch by protein; this can be shown by converting the equation to give the extract as a percentage on dry malt. This has been done for the nitrogen factor in the following table (Table 7), where the numbers in the top row refer to the equations so numbered in Table 6 (p. 428).

From Haase's well known statement that an increase of one per cent. in the protein content of barley corresponds with a decrease of one per cent. in the extract of the malt it would be expected that the nitrogen factors in this table would be about −5·8, implying that one per cent. of protein (nitrogen × 5·8) replaces one per cent. of starch. It may be noted here that the customary factor for converting nitrogen into protein, 6·25, is derived from animal proteins and is too large for plant proteins. The factor in these equations is, however, seen to be greater in most cases, than 5·8. The explanation of this lies partly in the effect of the amount of protein on malting loss; for besides replacing an equivalent percentage of starch, larger amounts of protein result in larger malting losses by increasing the amount both of rootlets and of respiration. This is brought to light also in Swedish results where the extract or starch content of barleys is measured. Such a method allows for replacement of starch by protein and for the effect of weight of grain, but it is found that the nitrogen content has to be taken into account as well. (R. Steenhoff. *Sven. Brygg. Foren.* 1927, 171). This is because the higher the nitrogen content of the barley the more potential extract is lost in malting.

The amount of malting loss and hence the nitrogen effect depends on the flooring conditions, *i.e.*, it increases with increasing rootlet growth and respiration. The size of the nitrogen factor is therefore a measure of the degree of "modification" (used here in a wide sense). For instance in 1923 (−5·20) and 1924 (−4·46) it would appear that on the average the barleys on which the equations were based were undermodified, while in 1925 (−9·16) they were overmodified. Independent evidence, to be published later, from the amount of permanently soluble nitrogen supports these conclusions, and with the 1924 barleys the maltster noted that

TABLE 7.

NITROGEN FACTORS FOR EXTRACT AS A PERCENTAGE ON DRY MALT.

(*N. Constants of Table* 6, *Multiplied by* 0.763).

Equation No.	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
N. Factor ..	−6·85	−5·20	−4·46	−9·16	−8·74	−6·48	−5·35	−7·95	−8·86	−8·55

"Another day's flooring would probably have improved the extracts."

The nitrogen factor in the equations has therefore a definite significance. Its size is the result of the replacement of starch by protein together with a varying addition due to the relation between the amount of malting loss and the amount of nitrogen present; and the magnitude of this addition depends on flooring conditions.

At first sight the equations in Table 6 (p. 428) appear so different that it looks as if the combined effects of season and of changed malting conditions were altering the relations so markedly that the equations would give very different results. This is not really so, for it will be seen from Table 8 that for the average barley the results are consistent though they differ more in the exceptional extreme cases. In this table are given the extracts calculated from the corresponding equations for "high extract," "low extract" and "average" barleys.

the barleys malted for the Barley Research was unsound malting material and in all these years the standard error is less than 1·0. It is lowest in the "vintage year" 1926.

The exceptional barleys in the bad years are those in which the observed extracts fall well below the calculated, and with these a low diastatic power coincides with a high sinker test, which indicates that many grains had not germinated. This surmise was confirmed by examining the stored samples in a diaphanascope. Large numbers of unmodified grains were seen in the exceptional samples. An empirical rule was noted here. The 1922 malts (where sinker test results are given) showed several exceptionally low results and in these the number of sinkers was greater than the diastatic power in Lintner degrees (D—S<0). When the diastase *minus* sinkers was between 0 and 20 the results tended to be about 0·7 lb. below average. When D—S>20 then the extracts

TABLE 8.

EXTRACTS CALCULATED FROM THE EQUATIONS IN TABLE 6.

Variety.	Plumage-Archer							Spratt-Archer		Plumage-Archer.
Equation No. ..	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
"High Extract" Barley, N = 1·2% G=42·0	101·0	102·2	100·3	102·4	101·4	103·0	101·0	104·1	105·5	104·3
"Average" Barley N = 1·5% G = 38·0 ..	98·0	99·4	98·3	97·4	97·4	99·6	98·1	100·2	101·2	100·2
"Low Extract" Barley, N=1·7 G = 32·0 ..	95·7	96·8	97·7	92·8	94·2	96·6	95·6	97·1	97·3	96·8

The variations seen in this table in the results calculated from equations based on stocking maltings are due in part to variations in the conditions of experimental malting which, as explained above, alter the size of the nitrogen factor, *e.g.*, the 1924 barleys were undermalted (on the average) as shown by the small nitrogen factor (see Table 7, p. 429) and supported by independent evidence. The other source of the larger discrepancies is individual barleys which have been experimentally malted, but would never have been malted in practice. In the years 1924, 1926, 1927, and 1928, only a small proportion of

tended to be 0·7 above average. The rationale of this rule would appear to be that the combined effects of lack of diastase and bad modification in many corns markedly reduce the extract. In the most striking case, barley No. 71, 1925, the diastatic power was 14 and there were 46 sinkers out of 100 corns (D—S=—32). This malt gave an extract 9·7 lb. below the calculated. Such barleys would never have been malted in practice and it is obvious that if they were omitted, the equations for 1922, 1923 and 1925 would have smaller standard errors.

The stocking equations are calculated for the Institute's experimental barleys (a very varied assortment) where the malting conditions are fixed for all barleys, malted at one time, whereas different barleys require different conditions for similar modification. Under these circumstances the stocking equations are of use only in establishing the validity of such predictions, and it must be emphasised that they are not regarded here as of practical value. In fact, in the "bad" years when many of the barleys were only of grinding quality and the fixed conditions clearly unsuited to all samples, the standard errors may be taken as a measure of the maximum possible error of the method.

The "Extract Equation."

It is only in 1926 that there are sufficient results of bulk maltings to yield a satisfactory equation. This equation (10), Table 6, (p. 428), does, however, appear to be reliable for Plumage-Archer barley of fair average malting quality malted under normal flooring and kilning conditions. The practical application of this equation has already been dealt with in Part I.

The standard error (0·68) is as low as in the best of the stocking equations.

Screening.

It is noteworthy that the nitrogen contents and thousand corn weights used are those of the barley "as received" while the bulk malting was done on screened samples. Apart from the removal of foreign matter this introduces no large errors into the predictions. The reason for this is, that the small grain removed from an unmixed sample (*i.e.*, barley of one variety and from one source) gives about the same extract as the corresponding bulk. Although the size of the smaller grain tends to reduce the extract yield, yet this is approximately counterbalanced by the fact that, in an unmixed sample, the smaller grain has a lower nitrogen percentage. Table 9 below gives some results which show this. Here results are given for samples of grain from various places which were separated by sieving into grain of different sizes and the nitrogen contents of the large and small grain were determined. Similar results are given for Hanna barley by Jalowetz (*Woch.-Brau.* 1917, **24**, 286).

A practical proof of this lack of screening effect on extract yield is given in Table 4 (p. 426) where the extracts of comparison maltings of screened and unscreened barleys are given. These even show a slight but clearly significant *reduction* of extract as a result of screening out small grain.

Effect of Malting Conditions.

It was indicated in Part I. that in the practical use of the "extract equation" it is sufficient to adjust the constant for different malting firms (see p. 425). It might be expected that varying malting conditions between individual floors or the effects of soil and season on extract would be large enough to make the equation valueless. Both of these possible sources of variation are affecting the accuracy of the results in Table 2 (p. 423). But, since in this table the differences between obtained and predicted extracts are fairly constant for one maltster, even from year to year, it is concluded that within one season the piece to piece variations should be small enough to be negligible in practice. It is hoped that further evidence on this point will be available in the near future.

The "extract" equation will in any case give a relative estimate of the extract-yielding power of barleys and it can be converted to give absolute values for any maltster. As indicated in Part I. adjustment of the constant appears sufficient in most cases. When conditions are markedly different from those in the bulk maltings studied, then adjustment of the nitrogen factor also becomes necessary. For, as demonstrated earlier (p. 429) the size of this varies with the degree of modification.

In Table 2 (p. 423) it is also shown that one maltster may obtain extracts which are on an

TABLE 9.

Relation between Weight of Grain and Nitrogen Content.

	Standwell Cannington 1928		Standwell Leegomery 1925		Standwell Leegomery 1927		Standwell Rothamsted 1928		F.122 Long Sutton 1926	
1,000 corn weight dry ..	50·28	39·44	49·91	39·52	48·51	37·52	50·23	40·55	35·31	20·80
Nitrogen percentage ..	1·917	1·625	1·517	1·337	1·880	1·654	2·235	1·972	1·396	1·381

average 1·0 lb. more than the predicted. Another may obtain 0·5 lb. less than the predicted. Such a comparison of obtained and predicted results affords a method of comparing the results of different malting methods even with different barleys. This comparison of extract yield is obviously not everything in comparing malting values.

In the experimental stocking maltings it appears that the conditions varied more from year to year than in the bulk maltings. The changes can best be followed by comparing among themselves the calculated results in Table 8 (p. 430). It must be remembered that part of the variation here is due to the badly germinating samples malted. These have lowered distinctly the values for the "low extract" barleys in 1922 and 1925 (Equations Nos. 1, 4 and 5).

EFFECT OF SOIL AND SEASON.

Soil and season have marked effects on extract yield through their effects on nitrogen content and thousand corn weight. These are allowed for in the equation and, apart from these, soil and season have no important effects on extract. Conditions of harvest weather and subsequent storage which lead to bad germination form the one exception to this dictum. The evidence for the lack of soil and seasonal interference with the prediction may be indicated as follows :—

(a) *From the bulk results.*

The major part of the variations in Table 2 (p. 423) may be accounted for by the variation between different malting firms and the sampling and analytical errors. Differing soils and seasons cannot therefore be causing any very marked effects on the differences between observed and predicted extracts, although any such effects cannot be clearly separated here.

(b) *From the experimental stocking malts.*

A study of the differences between observed and predicted extracts for successive years shows no indication of a regular relation with the nature of the soil or the rainfall. In one case, the Plumage-Archer controls to the variety plots (N.I.A.B.), it is possible to test the significance of the place variance compared with the total variance. The result (of a Z test) shows that there is no significant difference between places. That is, the variations come from the individual samples and all the samples from one place are not influenced in one direction by the nature of the soil or the weather. Similarly the experimental malting results from year to year show no marked effects of season. This is indicated by the similarity of the results in Table 8 (p. 430). Differences shown here from year to year may be accounted for by differences in malting conditions (from external evidence and from the nitrogen factor) and by varietal differences. The general values in Table 8 are lowered in some cases by the strikingly exceptional barleys, occurring chiefly in the bad seasons, whose extracts fall well below the predicted results. As mentioned above these variations can be accounted for by bad germination, resulting in bad modification and lowered diastatic power.

Such bad germination is the result of harvest weather and subsequent storage conditions and this is the only soil or seasonal effect which could be traced. In the good years, when all the barleys germinated well, the standard errors (0·65-0·95) may be low enough to be due only to errors caused by sampling and analysis; but though there may be another cause of variation which is not yet traced, it cannot be very important. Immature barleys might, as a result of the poor germination, give extracts below those predicted.

EFFECT OF VARIETY.

The Institute of Brewing analyses of the barley varieties grown by the National Institute of Agricultural Botany would afford very good material for variety equations if there were more analyses of each variety. The few available direct comparisons of varietal effect show that the increases for Spratt-Archer over Plumage-Archer range from 0 to + 1·0 lb. Probably +0·5 lb. represents the varietal difference accurately enough at all nitrogen contents and thousand corn weights.

The yield of extract per acre is probably about the same for the two varieties since they both give about the same yield of grain and nitrogen content on the same soil, but Plumage-Archer has significantly larger grain. This would approximately compensate for the fact that Plumage-Archer grain gives slightly lower extract than Spratt-Archer grain of corresponding thousand corn weight and nitrogen content.

It has only been possible to test the equation for these two varieties but it appears probable that the equation given may be found to apply to other two-rowed varieties with similar small modifications.

Bearing of the Results on "Quality" in Barley.

The amount of extract yielded as malt is a factor which affects the value of barley, but simple arithmetic will demonstrate that with the higher valued barleys by far the greater part of the greatly increased price is not paid for the increased extract. It now appears possible for a valuer to calculate the amount of extract. Therefore this factor in value can be measured leaving the less tangible factors in quality and value to be elucidated separately.

Another factor in "quality" is the amount and nature of the nitrogen compounds in wort. A determination of the nitrogen content of the barley is needed for the extract prediction and a later communication will show how this figure may be simultaneously of value in indicating the nitrogenous composition of the resulting wort.

SUMMARY.

As the result of a statistical study *it is established beyond doubt that there is an inverse relation between the nitrogen contents of barley of one variety and the extract yield of the resulting malt. An increase of extract with increase of grain size is demonstrated almost as conclusively.* Soil and seasonal conditions appear to affect the extract only through their effects on nitrogen content and thousand corn weight. The one exception to this is due to conditions which give badly germinating samples. These give low extracts.

It is suggested that, for the purpose of valuation and malting control, the extract a barley should yield as malt can be predicted accurately enough from an equation allowing for the effects of the amount of proteins and for the grain size. Such an equation can be constructed for each separate variety wherever the necessary data are available for a set of malts of similar modification. A series of maltings of a pure line of *Plumage-Archer* barley gave the following "extract equation" which probably gives results for average modification :—

$$E = 110{\cdot}1 - 11{\cdot}2 \times N + 0{\cdot}18 \times G.$$

Where E = the extract of the *dry* malt in lb. per quarter.

N = the nitrogen content on *dry* barley, and

G = the weight of a thousand *dry* corns in grms.

This equation predicts the extracts of the malts examined within 0·7 lb. in 68 per cent. of the cases. It was applied to other bulk maltings made in different years by different maltsters and predicted within 1·1 lb. the extracts obtained in 68 per cent. of the cases. It can be adjusted to meet the requirements of most maltsters simply by adjustment of the constant (110·1), when the error will probably not be more than about 0·8 lb. in 68 per cent. of the cases. 95 per cent. of the extracts are predicted with an error less than twice the values given.

The equation was found to apply to *Spratt-Archer* barley if a constant of 110·6 is substituted. Other varieties can probably be dealt with by equations of the same type.

The "extract equation" is given as a type of the formula necessary and not as a rigid equation applicable to all conditions. However, the available tests with very diverse conditions suggest, that in most cases it will be sufficient for practical purposes to add to, or subtract from the constant (110·1), the average difference between a number of predicted and observed results. The size of the nitrogen factor varies with, and is a measure of, the degree of modification during malting. So that an equation of closer approximation can be obtained by the statistical examination of the results of any given maltings.

A simple slide rule can be constructed to give the results or reference may be made to the table given as an Appendix (Table 10 p.434). The required estimations of nitrogen content, thousand corn weight and moisture content can be carried out fairly rapidly and especially rapid methods for each estimation are being studied. If these are satisfactory it should be possible to complete the estimations within one to two hours.

It must be strongly emphasised that if such a scheme is adopted the sampling must be most carefully done. Small samples should be taken, even from the screened barley or the finished malt, from all over the bulk and should be well mixed to give the final sample for analysis. An error of 0·1 per cent. of nitrogen on dry matter, or, of 5 grms.

in the thousand corn weight results in an error of 1 lb. in the prediction.

Equations of the type given appear to have a wide range of applicability and it would indeed appear that if the sampling and analyses have been correctly carried out, the equation can be regarded, not as a rough approximation, but rather as a standard of reference with which the results obtained may be compared. That is, a comparison of the predicted results with those obtained will measure the success of the conditions in producing extract and their suitability for given barleys.

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APPENDIX.

FOR PRACTICAL USE.

TABLE 10.

TABULATED VALUES OF EXTRACT ON DRY MALT FROM EQUATION $E=110.1-11.2\times N+0.180\times G$.

1,000 corn weight	Nitrogen Percentage (on dry barley).														
	1·10	1·15	1·20	1·25	1·30	1·35	1·40	1·45	1·50	1·55	1·60	1·65	1·70	1·75	1·80
42·0 & over	105·3	104·8	104·3	103·7	103·1	102·6	102·0	101·5	100·9	100·3	99·8	99·2	98·6	98·1	97·5
40·0	105·0	104·4	103·9	103·3	102.8	102·2	101·6	101·1	100·5	100·0	99·4	98·8	98·3	97·7	97·2
38·0	104·6	104·1	103·5	103·0	102·4	101·8	101·3	100·7	100.2	99·6	99·1	98·5	97·9	97·4	96·8
36·0	104·3	103·7	103·2	102·6	102·0	101·5	100·9	100·4	99·8	99·2	98·7	98·1	97·6	97·0	96·4
34·0	103·9	103·3	102·8	102·3	101·7	101·2	100·6	100·0	99·5	98·9	98·3	97·8	97·2	96·7	96·1
32·0	103·5	103·0	102·5	101·9	101·3	100·7	100·2	99·6	99·1	98·5	97·9	97·4	96·8	96·3	95·7
30·0	103·2	102·6	102.1	101·5	101·0	100·4	99·8	99·3	98·7	98·1	97·6	97·0	96·5	95·9	95·3
28·0 grms.	102·8	102·3	101.8	101·2	100·6	100·0	99·5	98·9	98·4	97·8	97·2	96·7	96·1	95·6	95·0

This is for Plumage-Archer barley. For Spratt-Archer add 0·5 lb.