

THE RELATIONSHIP BETWEEN SPECIFIC GRAVITY AND PERCENTAGE DRY MATTER IN POTATO TUBERS^{1,3}

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Abstract

Specific gravity and percentage dry matter were determined for 1269 potato samples taken over a period of six years. The correlation coefficient between these properties over the whole material was 0.912 and the regression equation was:

$$\% \text{ dry matter} = -217.2 + 221.2 (\text{specific gravity}).$$

When the material was broken down into smaller, logically defined groups, such as a single cultivar, regression lines often deviated from this general line, although in most cases the correlation coefficients were still quite high. This means that the quantitative relationship between specific gravity and dry matter content was not sufficiently stable to serve as a general measure of prediction under all conditions. It seems probable that various production areas of the United States will have to develop the line which is best suited to their conditions, and that some cultivars may require separate lines.

Resumen

Se determinó la gravedad específica y el porcentaje de materia seca en 1269 muestras de papa tomadas sobre un periodo de seis años. El coeficiente de correlación entre estas propiedades sobre el total del material fue 0.912 y la ecuación de regresión fue:

$$\% \text{ materia seca} = 217.2 + 221.2 (\text{gravedad específica})$$

Cuando el material fue separado en pequeños, lógicamente definidos, grupos tales como un solo cultivar, las líneas de regresión a menudo se desviaban de esta línea general, aunque en la mayoría de los casos los coeficientes de correlación fueron aun muy altos. Esto significa que la relación cuantitativa entre gravedad específica y contenido de materia seca no fue suficientemente estable para servir como una medida general de predicción bajo todas las condiciones. Parece probable que varias áreas de producción de los Estados Unidos tendrán que desarrollar la línea que más se adapte a sus condiciones y que algunos cultivares puedan requerir líneas separadas.

Introduction

The importance of dry matter content of potato tubers in relation to texture of the cooked or baked tuber or to yield and quality of processed

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product has been reported in many publications (for reviews see 3, 10, 12). The advantage of measuring the percentage dry matter by the rapid and simple method of specific gravity is obvious. It remains to be shown that the relationship between specific gravity and dry matter not only is qualitatively close, witness the many correlation coefficients of 0.85 and higher reported in the literature (1, 4, 8, 15), but also quantitatively stable. Conscious attempts to investigate this, however, are few (1, 14). Vanasse et al. (14) found significant differences in regression equations derived from samples of different cultivars or different locations, but considered these differences of little practical importance. Agle and Woodbury (1) found differences due to growing season in the cultivar Russet Burbank and, sometimes, a tendency for the regression coefficients to increase during storage.

A regression analysis of the results of measurements published by Behrend et al. (2) on which a well known table is based (Maercker's table) shows that there were significant differences between the regression lines calculated for subgroups of their material, depending on the years in which the samples were taken and on who did the determination (1872 and 1873 (n=28) by Abesser, 1874 and 1875 (n=72) by Holdefleiss and 1876 and 1877 (n=44) by Morgen). The slope of the line fitting the results of Holdefleiss was significantly steeper than the one calculated for the results of Morgen. The level of the line calculated for the material of Abesser was significantly lower than the levels of both other lines.

An analysis of the material published by Hals and Buchholz (6) shows that the line calculated for their 1907 samples (n=74) was significantly different in both level and slope from the line calculated for their 1908 samples (n=70).

The data of Tuorila (13) indicate that soil type had an influence on the relationship, since the regression line calculated for samples from oligotrophic peat soil was at a significantly higher level than the line calculated for samples of the same harvest date for eutrophic peat soil.

Regression lines can be constructed from the results of Porter et al. (7) indicating that they were dependent on growing conditions. The line representing the samples (n=21) from Long Island, New York, was at a significantly lower level (approximately 1% in dry matter) than the one from Idaho (n=25), but there was no difference in slope.

A commonly used regression line is the one published by von Scheele et al. (8) that was based on European cultivars and growing conditions. Fitzpatrick et al. (5) stated categorically that it is not satisfactory under American conditions. They felt it would be possible to produce, through a cooperative project using standardized procedures, a common regression line with narrow confidence limits. The examples previously mentioned, however, suggest that it is very unlikely that a regression formula will be found that is suitable under all conditions.

A large number of specific gravity and dry matter measurements had been taken at this station over the years and it seemed likely that the collection and organization of these data would contribute to the knowledge of the relationship between these two factors, particularly since nearly all samples were grown at the same location. The present paper is the result of these studies.

Methods

Specific gravity measurement—Specific gravity was determined by calculating the quotient
$$\frac{\text{weight in air}}{\text{weight in air minus weight in water}}$$

Sample sizes varied according to the type of experiment. A sample weight of 5 kg was normal for measurements shortly after harvest, but if specific gravity was measured during or after storage experiments, the weights were usually 2.0 to 2.5 kg.

Dry matter determinations—Sectors were cut lengthwise out of each of 12 to 15 tubers, which insured a proportional representation of all tuber tissues, and destroyed in a blender after adding an equal weight of water. Duplicate samples of approximately 40 g of slurry were weighed into 10 cm Petri dishes and dried for 16 hours at 70°C in a ventilated oven. Since the surface area of the material in the dishes was large and the thickness not more than 5 mm, the relatively short drying time of 16 hours was more than adequate. A temperature of 70°C or slightly lower was maintained in order to prevent the starch from gelatinizing. The resulting dry matter was a very friable substance which was easily removed from the dishes.

Statistical analysis—Correlation coefficients and regression equations with standard errors were calculated, and the significance of differences in level and slope between comparable lines was established in paired comparisons by the method mentioned by Snedecor (11).

Material

The results of 1269 samples from field and storage experiments were subdivided into four groups as follows.

I. Variety trials—The material in this group came from variety trials which were carried out in 1969, 1970, 1971 and 1972. In 1969 the variety trial consisted of 18 cultivars in duplicate in which the determinations were carried out on October 20, 1969. In addition, one sample of each cultivar was stored at 5°C, one at 7.5°C and one at 10°C until December 26, 1969, when the experiment was terminated and the specific gravity and dry matter content determined. There were also 32 lines in an observational trial of breeding material in which the determinations were done on October 7, 1969. (Total 1969: 122 samples). In 1970 there were 25 cultivars in the variety trial. The specific gravity was determined on September 21,

1970; the dry matter was determined on November 26, 1970, after the tubers had been stored at 7.5°C. (Total 1970: 25). In 1971 the variety trial consisted of 41 cultivars in which the determinations were done on October 27, 1971. In addition, 12 samples of the cultivar Norchip were included which came from various places within the State of New York. The determinations were done in November 1971. (Total 1971: 53). In 1972 there were 36 cultivars in the variety trial. Specific gravity was determined on October 10 and dry matter content on November 20, 1972, in tubers from two field replications. (Total 1972: 72). The total number of samples of these four years of variety trials was 272.

II. Storage experiments—In these trials potato tubers were kept in closed metal containers in which the temperatures and relative humidities were kept constant (9). Temperatures were always 7.5, 10.0 and 12.5°C, relative humidities were in 1971 approximately 70, 80 and 100%, in 1972 they varied from 60 to 100% in five steps, and in 1973, 65, 70 and 95%. Every year there were 144 samples stored in these containers, four in each, but in 1971 two samples were lost. The total number was 430.

In 1971 the cultivar Norchip was sampled eight times, every fourth week, starting November 14, 1971, and ending May 22, 1972. In 1972 the variety Katahdin was sampled four times: December 13, 1972, January 17, February 12 and March 28, 1973. In 1973 Hudson, Katahdin, Kennebec and Russet Burbank were sampled April 2, 1974.

III. Nitrate studies—Samples of Katahdin tubers of varying maturity were collected from plots with different nitrogen fertilization treatments. Tubers were harvested at weekly intervals, starting July 11 in 1972, June 20 in 1973 and July 8 in 1974. At each harvest date samples of 8 (1972) or 9 (1973 and 1974) treatments were harvested in duplicate. Specific gravity and dry matter content were determined the same day. Total: 427.

IV. Variety-fertility—In 1974, a similar experiment included five varieties (Alamo, Cascade, Hudson, Katahdin, Superior) and four nitrogen fertilization treatments. Weekly harvests began July 1, 1974. There were 140 samples.

Results

The relevant numerical results are given in Table 1 and the regression lines are shown in Fig. 1-4. Care has been taken not to extrapolate the regression lines beyond the limits of the specific gravity range of the material covered in each experiment. In Fig. 1 the line of von Scheele has been added and in all figures the line for the total material has also been drawn. Fig. 1 indicates that the regression line for the total material and the lines for the four groups paralleled the line of von Scheele, but the levels were higher. Regarding the four groups, the slope of group III was

TABLE 1.—*The relationship between specific gravity and dry matter content of potatoes grown on Long Island, N. Y.*

	n	Specific gravity		% dry matter	corr. coeff. r	Regression of percentage dry matter on specific gravity				
		Av.	Range*			Av.	Range*	Intercept a	Slope b	sb
I. Variety trials										
1969	122	1.0667	1.0472-1.0862	19.66	13.9-25.5	0.915	-270.2	11.7	271.7	11.0
1970	25	1.0627	1.0475-1.0779	18.64	14.2-23.1	0.944	-281.4	21.8	282.4	20.5
1971	53	1.0680	1.0483-1.0877	18.89	14.2-23.6	0.938	-222.1	12.4	225.6	11.7
1972	72	1.0707	1.0541-1.0873	19.01	15.0-23.0	0.956	-229.3	9.1	231.9	8.5
Total	272	1.0677	1.0488-1.0866	19.25	14.2-24.3	0.881	-233.6	8.3	236.8	7.8
II. Storage experiments										
1971	142	1.0698	1.0592-1.0804	19.04	16.7-21.4	0.820	-173.2	11.4	179.7	10.6
1972	144	1.0714	1.0625-1.0803	20.17	18.4-22.0	0.891	-173.4	8.3	180.7	7.7
1973	144	1.0755	1.0623-1.0887	20.86	17.3-24.5	0.816	-217.2	14.2	221.3	13.2
Total	430	1.0722	1.0602-1.0842	20.03	17.0-23.1	0.841	-209.8	7.2	214.4	6.7
III. Nitrate studies										
1972	112	1.0649	1.0587-1.0711	17.96	16.3-19.6	0.750	-191.8	17.6	197.0	16.6
1973	153	1.0545	1.0382-1.0708	16.57	13.0-20.2	0.946	-203.1	6.1	208.3	8.8
1974	162	1.0628	1.0473-1.0783	17.78	14.0-21.6	0.893	-215.6	9.3	219.6	8.8
Total	427	1.0604	1.0438-1.0770	17.39	13.9-20.9	0.905	-185.6	4.6	191.4	4.4
IV. Variety-fertility										
1974	140	1.0606	1.0477-1.0735	16.93	13.6-20.3	0.902	-230.9	10.1	233.7	9.5
Total Material	1269	1.0660	1.0474-1.0846	18.63	14.1-23.1	0.912	-217.2	3.0	221.2	2.8

*Range: Average minus twice the standard deviation to average plus twice the standard deviation.

significantly ($P < 0.01$) less than the slopes of the other three lines. All differences in level were highly significant.

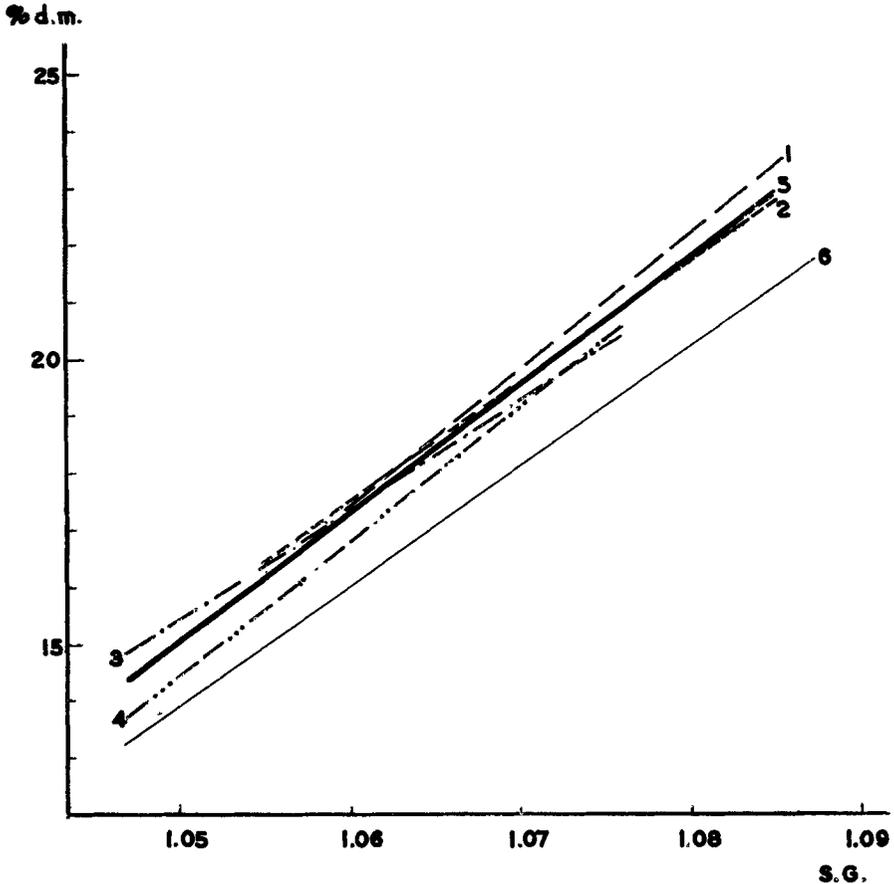


FIG. 1. Regression lines of percentage dry matter on specific gravity (1: Variety trials; 2: Storage experiments; 3: Nitrate studies; 4: Variety-fertility; 5: Total material; 6: von Scheele's line).

Differences Between Years

An unbiased assessment of the year influence is not possible since in many cases this influence was at least partly confounded with the cultivar influence. For instance, the cultivars included in the variety trials were different each year, and in the storage experiments Norchips were used in 1971, Katahdin in 1972 and these two plus two others in 1973. Still, the finding of significant differences between years would prove that the relationship between specific gravity and dry matter content is not constant, regardless which of the influences predominates.

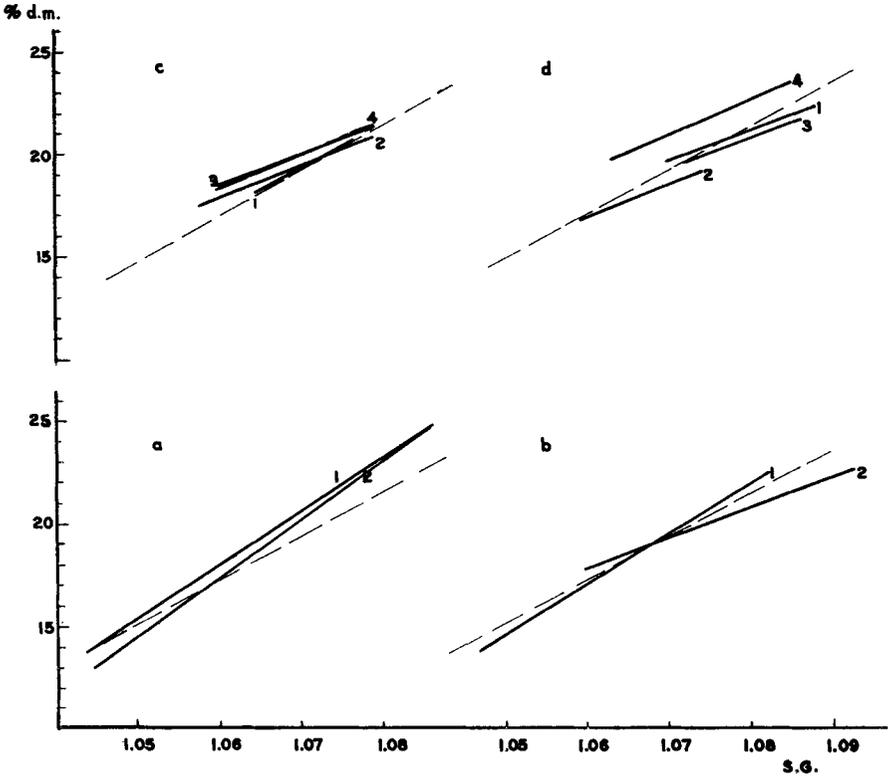


FIG. 2. Regression lines of percentage dry matter on specific gravity (a: Variety trials; b: Storage experiments; c: Nitrate studies; d: Variety-fertility; Broken lines: Total material).

I. Variety trials—The results of the 1971 trial were such that its regression line virtually coincided with the line for the total material (Fig. 2a). All differences in level between the various years were highly significant except the one between 1969 and 1970. Differences in slope were significant except those between 1969 and 1970 and between 1971 and 1972. Since the dry matter determinations were done much later than the specific gravity measurements in the 1970 samples, this may be an explanation for the steepness of the line, but this cannot be an explanation for the 1969 samples.

II. Storage experiments—The regression coefficient for 1973 was greater ($P < 0.01$) than the regression coefficients in both other years (Fig. 2b). The level of the line of 1971 was significantly ($P < 0.01$) lower than the other lines. However, differences in both respects were small.

III. Nitrate studies. Differences in slope among the lines for the three years were nonsignificant, but all differences in level, although small, were highly significant (Fig. 2c).

Influences Within Years

In some experiments the material was divided into smaller groups in order to identify the influences at work. Results are shown in the form of regression lines only (Fig. 3 and 4).

I. Variety trials. In the trial of 1969 five subgroups were made: the observational trial shortly after harvest, the variety trial shortly after harvest, and the variety trial after storage at 5, 7.5 and 10°C. There were no differences in slope between any two of the subgroups of the variety trial, but there were significant differences in level between the observational trial and the other groups. The regression lines of the observational trial and the other groups combined are given in Fig. 3a. The correlation coefficients were 0.910 and 0.919, respectively.

In 1971 a distinction can be made between the regular variety trial ($r=0.953$) and Norchips samples of various origins ($r=0.873$). There was a

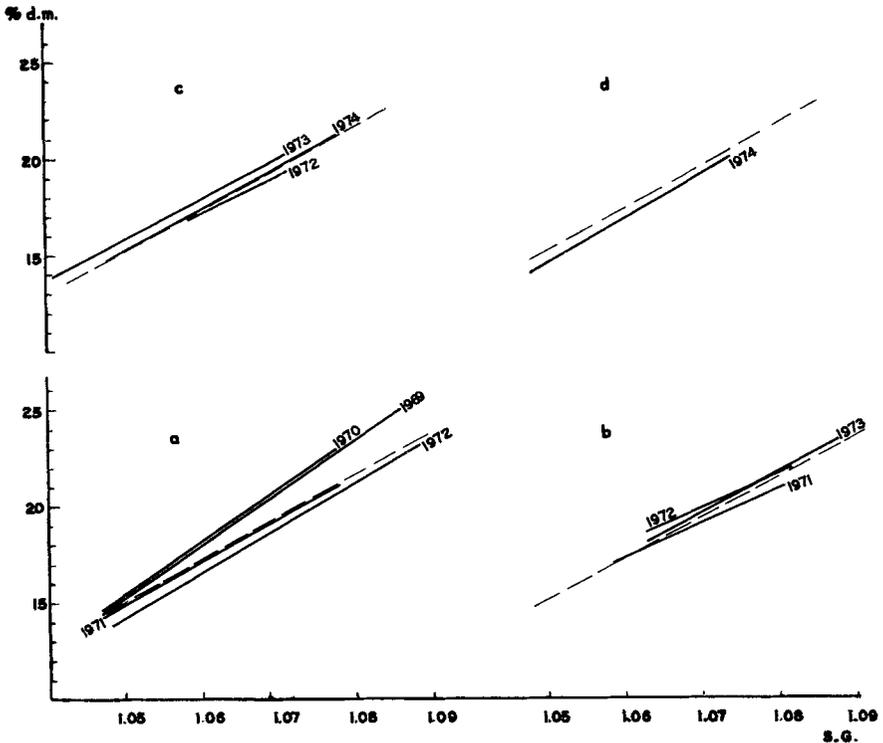


FIG. 3. Regression lines of percentage dry matter on specific gravity (a: Variety trial 1969, 1. regular variety trial, 2. observational trial; b: Variety trial 1971, 1. regular variety trial, 2. Norchips of various origins; c: Storage experiments 1972; 1. December, 2. January, 3. February, 4. March; d: Storage experiments 1973, 1. Hudson, 2. Katahdin, 3. Kennebec, 4. Russet Burbank; Broken lines; Total material).

significant difference in slope but no difference in level between groups (Fig. 3b).

II. Storage experiments—Results of the eight sampling dates in 1971 were analyzed separately and in this very homogeneous material differences in specific gravity and percentage dry matter were too small for high correlations to appear. When sampled after four weeks of storage, the correlation coefficient was only 0.633, and after eight weeks 0.690. At later dates the influence of the strongly varying storage conditions became visible in the spread in specific gravity of the material, and the correlation coefficient rose until it became stable at approximately 0.92 after 24 weeks of storage. There were no differences in slope between lines, but the level of the line in January (after twelve weeks of storage) was unexplainably at a much higher level than the others.

The four sampling dates of 1972 gave much greater differences. The line for December (first sampling date) had a regression coefficient which was greater ($P < 0.01$) than the other three lines, and the levels for the February ($r = 0.813$) and March ($r = 0.912$) sampling dates were at a higher ($P < 0.01$) level than the December ($r = 0.811$) and January ($r = 0.957$) lines (Fig. 3c).

In 1973, when four varieties were stored for only one period, all differences in level were highly significant. The fact that these lines occupied such varying levels greatly affected the overall regression coefficient of the experiment (Fig. 3d). While the regression coefficients for the four varieties separately varied from 156 to 178, the overall regression coefficient was 221. The data for Russet Burbank in particular, fell outside the swarm of dots. The correlation coefficients were 0.857 for Hudson, 0.758 for Katahdin, 0.652 for Kennebec and 0.837 for Russet Burbank.

III. Nitrate studies—In these experiments the material was divided into maturity groups by combining certain harvest dates. In 1972 the correlation coefficient of the combined material of the first three harvest dates (July 11-25) was 0.847, rather satisfactory considering the narrow range in specific gravity, but the correlation coefficients of the two following groups of two harvest dates were very low, 0.617 and 0.593. Even after combining these two groups into one, the correlation coefficient increased to only 0.637. It is remarkable not only that the range in specific gravity was so narrow, 1.058 to 1.070, but, particularly, that this level was reached as early as mid-July. Undoubtedly, the weather conditions, which also resulted in very low yields, caused these anomalies. The only difference found was the one in level between the first groups of three and the second group of four harvest dates (Fig. 4a).

In 1973 the results conformed more closely to expectations. The absence of differences in level or slope indicates that the relationship between specific gravity and dry matter content was not affected by matur-

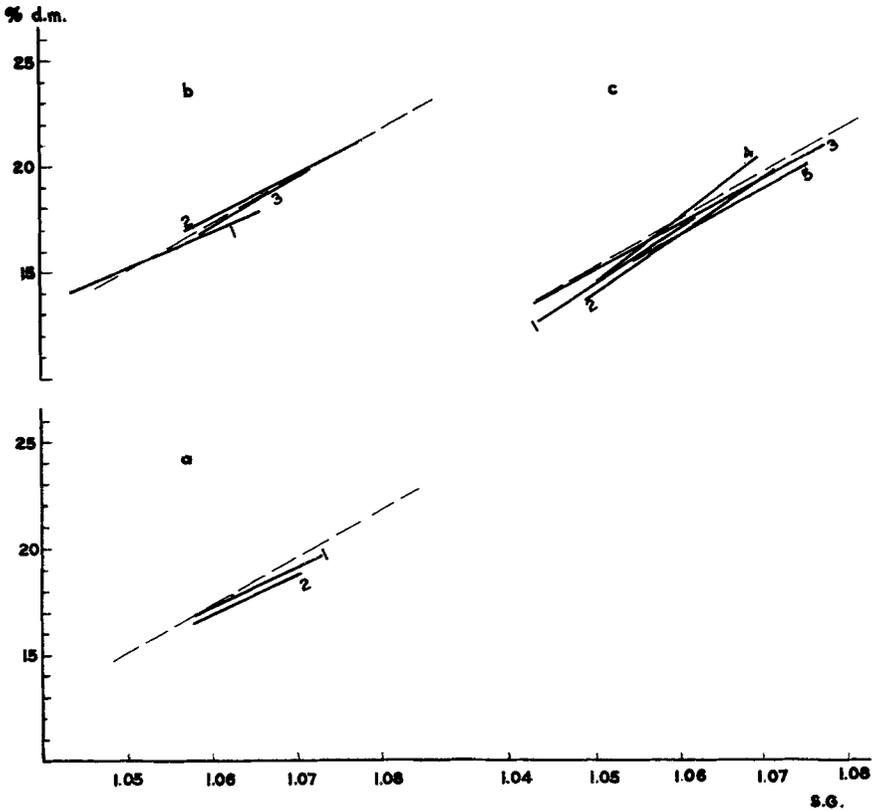


FIG. 4. Regression lines of percentage dry matter on specific gravity (a: Nitrate studies 1972, 1. First 3 harvests, 2. Remaining 4 harvests; b: Nitrate studies 1974, 1. First 3 harvests, 2. Second 3 harvests, 3. Last 3 harvests; c: Variety-fertility 1974, 1. Alamo, 2. Cascade, 3. Hudson, 4. Katahdin, Broken lines: Total material).

ity. The correlation coefficients were 0.815, 0.842 and 0.614 for the three consecutive groups of three harvest dates.

In 1974 there was a highly significant difference in level between the first and the second group of three harvest dates, but not between the second and the third. There were no differences in slope (Fig. 4b). The correlation coefficients were 0.833, 0.816 and 0.726, respectively.

IV. Variety-fertility—Because of the small number of samples for each variety no subdivision in maturity groups was made. The variety influence on the relationship between specific gravity and dry matter content was considerable. The slope of the line of Katahdin ($r=0.917$) was significantly greater than the slopes of the lines of Hudson ($r=0.938$) and Superior ($r=0.855$). The differences in slope between Hudson and both Cascade ($r=0.948$) and Alamo ($r=0.943$) were also significant ($P<0.05$). The only

difference in level was that between Katahdin and all the other varieties ($P < 0.01$) (Fig. 4c).

Discussion

It is clear that von Scheele's regression formula of dry matter content on specific gravity is not applicable to tubers grown on Long Island. The difference between his line and the regression line for the total material of 1269 samples was more in level than in slope. At any level of specific gravity the dry matter content of the tubers predicted by the line best adapted to this material was 1 to 1.5 percentage units higher than results predicted by von Scheele's formula.

An important question is how well the line fitting the total material is able to predict the dry matter content in different years or with different varieties. It is clear from the results shown in Fig. 1 to 4 that the further the material is broken down into smaller, logically defined groups, the more frequent the deviations from the general line become. In 1969 and 1970, for instance, the regression lines for the variety trials deviated considerably from the general line, but in the storage experiments and the nitrate studies these differences were not so pronounced. A further breakdown into smaller units sometimes resulted in considerable deviations, for instance, in the storage experiment of 1973 and the variety-fertility trial in 1974. Since these differences were statistically significant, it follows that a general line would be insufficiently stable for use under all conditions. Nevertheless, adoption of the general line for Long Island potatoes would certainly be an improvement over the von Scheele line.

One factor, which had only a minor impact on the relationship between specific gravity and dry matter content, was the maturity of the tubers. Although some significant differences were found, they were only present if very young tubers were involved. Later during the growing season the relationship seemed to become stable. A second factor which did not have a very great influence was the duration of storage. In two out of three cases (variety trial 1969 and storage experiment 1971) there was no influence at all, but in the third (storage experiment 1972) an increase in level of the regression line was found, although not an increase in slope, as has been reported (1).

A breakdown by cultivars sometimes caused large differences in regression lines and this points to the possibility that some varieties may require separate lines.

Although the statement made by Fitzpatrick et al. (5) that von Scheele's line "now borders on the obsolete for American potatoes" certainly applies to Long Island tubers, it, nevertheless, may be an exaggeration. The results of these experiments show that change in the relationship between specific gravity and dry matter content can be caused by

various factors and that, under certain conditions, von Scheele's line still might be satisfactory. In fact, in some publications, particularly from Idaho, results have been reported which agree with von Scheele's line (15). In view of this, the hope expressed by Fitzpatrick et al. (5) that it should be possible to produce a regression curve with narrow confidence limits suitable for industrial use for all of the United States seems too optimistic. It seems more likely that regression formulas will have to be adapted to growing areas and possibly also to cultivars.

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