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Adapting the Standard Air-Oven Method For "Quick" Determination of the Moisture Content of Small Seeds

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Summary

THE need for an accurate "quick" method of testing small seeds for moisture content stimulated an intensive investigation into the possibility of using one of the many commercially available testing devices for this purpose. Subsequent experimentation indicated that commercial units are neither sufficiently reliable nor accurate.

This situation led to a study of the behavior of seeds when dried in an air-oven. A statistical analysis of the rate of drying of a selected species, conditioned to several moisture levels, indicated that a linear relation existed between the percentage of moisture lost at the completion of a 2-hour drying period and the actual moisture content of the seed. From these data it was possible to construct curves and derive formulae which enable one to predict the actual moisture level of a seed sample by substituting the 2-hour reading in the appropriate formula. If carried out with reasonable precision, this method will yield results with an accuracy of $\pm$ 0.5 percent and should be of considerable value to seedsmen engaged in processing small seed for special packaging.

Adapting the Standard Air-Oven Method For "Quick" Determination of the Moisture Content of Small Seeds

JOHN E. TURNER*

Introduction

THE use of moisture testing in both agriculture and industry is widespread, but nowhere must the technique be applied with greater skill than in the seed industry, particularly that branch which specializes in the processing of small-seeded vegetables, legumes, and grasses for packaging in hermetically-sealed containers. The reason for the critical nature of the operation lies in the composition of the commodity itself. Seeds contain varying amounts of volatile organic substances which are readily dissipated if the ambient temperature is permitted to exceed 103° C by any significant amount. If the technique is carelessly applied, substances other than water may be lost and the resultant data will be inaccurate.

The moisture content of small seed being processed for packaging in air-tight containers usually must be reduced in order to render it safe for storage under these conditions. Drying may extend from a few hours to several days depending on the original moisture level and the type of equipment being used to extract the water. The seed lot is sampled periodically and moisture tests are made in order to determine the point at which conditioning may be suspended.

A conventional air-oven test for moisture requires 24 hours to complete and, as a consequence, a seed lot may be dried for a considerable period of time longer than necessary. A rapid air-oven test has been developed which reduces the drying time to 2 hours and is a technique which might be useful. A number of commercial moisture testers are described as being adapted for making rapid tests and should be investigated.

The purpose of this study was to test and evaluate techniques and apparatus available for quick moisture testing and to develop a method to meet the requirements of seedsmen engaged in the special packaging of small seeds.

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Literature Review

References to research on moisture testing are rather sparse. Nutile (1), using a commercial moisture tester, developed a satisfactory method for the rapid determination of the moisture content of peas, beans, and corn. No data on small seeds are presented. Turner (5) describes a technique for testing small-seeded vegetables with another commercial unit and the data indicate that when the device is operated in accordance with instructions, reliable moisture readings can be obtained.

The International Rules for Seed Testing suggest a rapid air-oven method to hasten moisture determinations (2). Essentially this consists of drying the seed at 130° C for a period of 2 hours, at which time the moisture content is calculated in the customary manner.

The U.S. Department of Agriculture handbook on seed testing (4) devotes a short chapter to moisture testing in which are described a number of oven and distillation methods, in addition to the use of electric meters for testing grains. The handbook further states that methods for determining moisture can be roughly placed in two categories: 1) those by which the moisture is driven off by heat and measured either gravimetrically or volumetrically and 2) rapid methods which are standardized against one of the basic methods.

Experimental

Evaluation of Available Methods and Apparatus

A number of moisture testers, representing several basic designs, were investigated to determine their usefulness for the rapid measurement of the moisture content of small seeds. None were found to be consistently accurate nor reliable. The most common limitations are summarized below:

1) In some instances the seed had to be ground or pulverized to make a test. The moisture which was unavoidably lost during this first step could not be measured and consequently there was no way to correct the final reading.
2) Some instruments were sensitive to low moisture levels.
3) Some electronic testers required the preparation of separate calibration charts for every size grade of each species tested.
4) Instruments utilizing various sources of heat to evaporate moisture quickly also presented the danger of charring and chemical decomposition.
5) None of the meters tested provided readings to an accuracy of ± 0.5 percent when calibrated against the air-oven method.

The usefulness of the rapid air-oven method was investigated and a series of exhaustive tests indicated that this technique was not reliable. A comparison of the results obtained with the standard air-oven method and that using the elevated temperature indicated that substances in addition to moisture were being driven off.

All data obtained pointed conclusively to the uniformity and reliability of the standard air-oven test, which consists of drying a sample for a period of 24 hours (48 hours for whole peas, beans, and corn) at a temperature of 101-103° C. At the completion of drying, the loss in weight is determined and the moisture percentage is calculated by means of the following relation:

$$\text{percent of moisture} = \frac{\text{loss of weight (moisture)} \times 100}{\text{original weight of sample}}$$

The Mechanics of Seed Drying

Since little is apparently known about the behavior of seeds as they dry in an oven it was decided to plot a series of curves in order to gain that insight. In addition, there was a possibility of developing a new approach to the moisture testing of small seeds. Kentucky bluegrass (*Poa pratensis*) was selected as an initial subject. Samples were conditioned to five moisture levels and dried in an air-oven at 101-103° C. (See page 6 for the descrip-

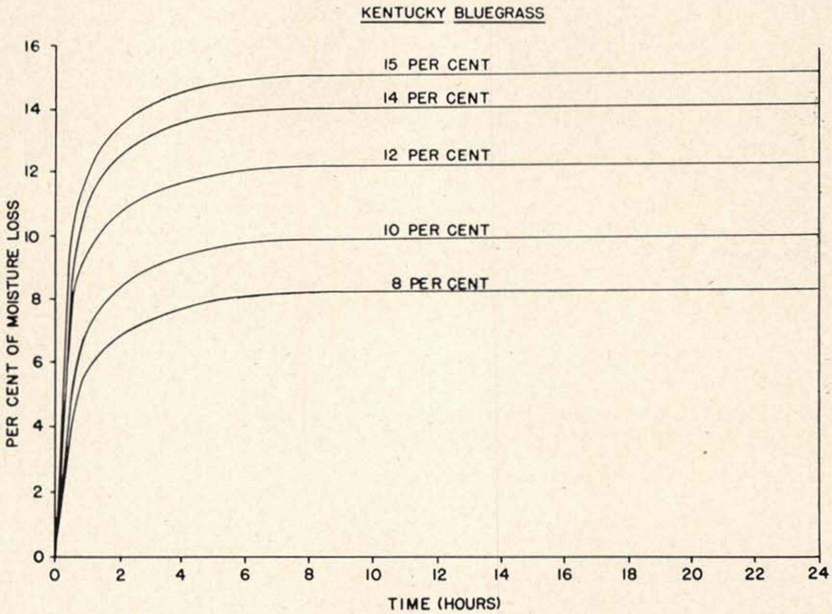

Figure 1.—Family of drying curves for Kentucky bluegrass seed showing rate of moisture loss, with original moisture content used as the parameter.

tion of the conditioning process and page 24 for the derivation of the formula used.) Samples were weighed at 30-minute intervals for the first 3 hours and then every hour for the next five readings. The final weighing was made at the end of 24 hours. Figure 1 is a plot of the resultant data and shows a family of drying curves, using seed moisture level as the parameter. The curves illustrate several rather significant features: 1) drying occurred at all moisture levels in a logarithmic manner, 2) 80 to 90 percent of the total moisture was driven off at the end of 2 hours and 3) all but 1 to 2 percent of the total moisture present was lost after 8½ hours.

The fact that 80 to 90 percent of the total moisture content of the seed was driven off within 2 hours suggested that it might be possible to predict, with reasonable accuracy, the total moisture present from a determination of the amount of water lost within 2 hours, together with the application of a suitable mathematical formula. The graph indicates, for example, that Kentucky bluegrass conditioned to 10 percent moisture lost significantly less water during a given time interval than 12-percent seed. The relation of the 2-hour moisture tests to the actual moisture content of the seed and to each other is not readily apparent from Fig. 1.

Before setting up a series of experiments to determine what, if any, correlation existed between the 2-hour and 24-hour drying periods, it seemed wise to examine the drying curves for several representative species in greater detail. Moisture content was

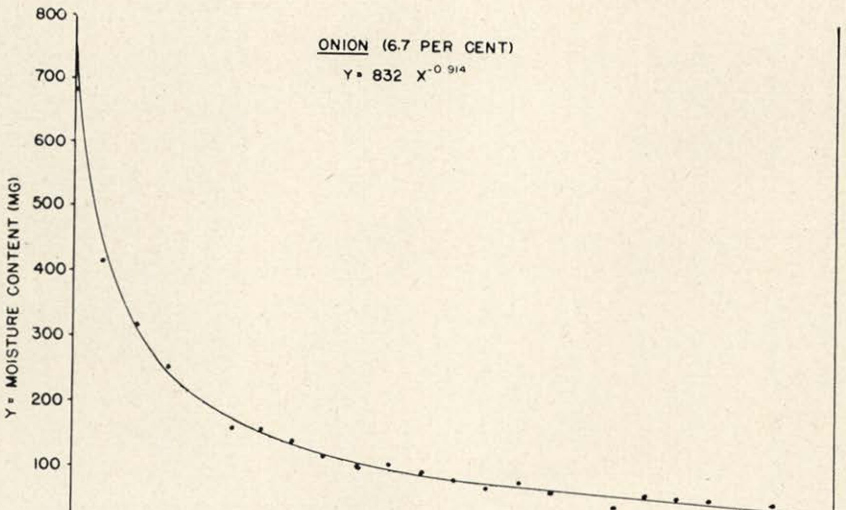

Figure 2.—Exponential drying curve for onion seed whose original moisture content was 6.7 percent.

plotted against time, at 15-minute intervals, for the following species: 1) onion (Fig. 2), 2) ryegress (Fig. 3), 3) *Poa trivialis* (Fig. 4), and 4) cabbage (Fig. 5). It will be noted that in all instances the drying curve assumed an exponential characteristic. Several types of graphs were tested and it was found that the curves could be converted into their linear form by plotting the logarithm of the seed moisture against the logarithm of the time interval. This is indicative of the power law with the general formula:

$$Y = kX^n$$

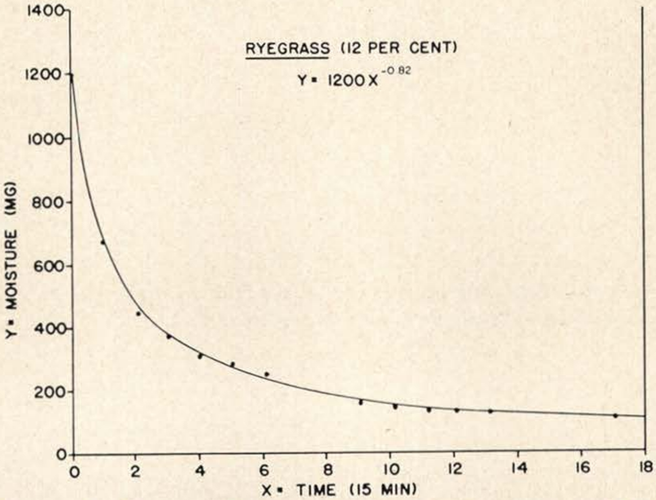

Figure 3.—Exponential drying curve for ryegrass seed whose original moisture content was 12 percent.

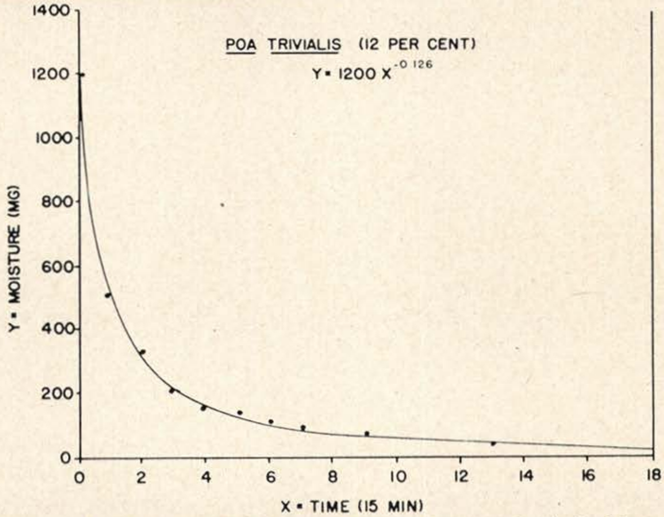

Figure 4.—Exponential drying curve for rough stalk bluegrass whose original moisture content was 12 percent.

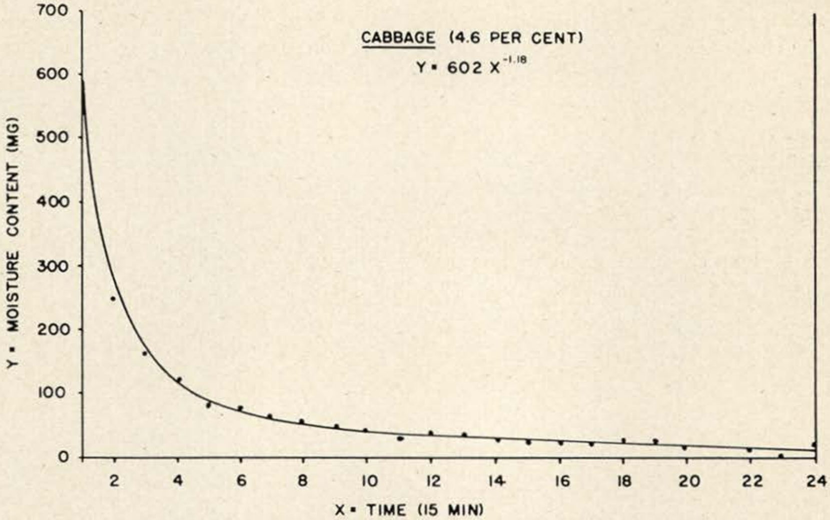

Figure 5.—Exponential drying curve for cabbage seed whose original moisture content was 4.6 percent.

Having developed linear curves in all instances, it was now possible to analyze the data statistically and derive the appropriate formulae. (See figures 6, 7, 8 and 9.)

Although the results were not particularly useful in themselves, the fact that the rate of moisture loss could be described mathematically lended considerable weight to the theory that the total moisture might be predictable from the 2-hour reading.

Methods and Materials

In order to provide test material in an uninterrupted series of moisture levels from 5 to 15 percent, seed samples were prepared in the following manner: A 24-hour air-oven test was made on a seed sample to determine its moisture content. If the seed moisture was higher than that desired for the lowest member of the series, the experimental material was dried in small cloth bags suspended in a warm room (approximately 90° F) for a period of about 2 weeks. It was essential that the room humidity be maintained at a low level so that the seed lost moisture, rather than absorbed it.

After the moisture content of the seed was lowered sufficiently, the remainder of the series was prepared by adding a precise quantity of water to a weighed amount of the seed. The amount of water was determined by the following mathematical relation:

$$V' = (md / 1 - m) - w,$$

where V' = wt. of water to be added
m = desired moisture ratio
d = dry wt. of sample
w = wt. of water present in original sample

(See page 24 for derivation of formula.)

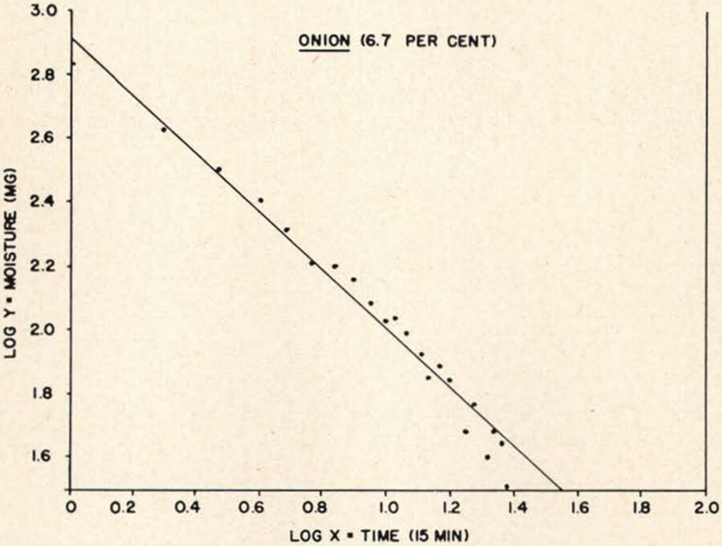

Figure 6.—Linear drying curve for onion seed whose original moisture content was 6.7 percent.

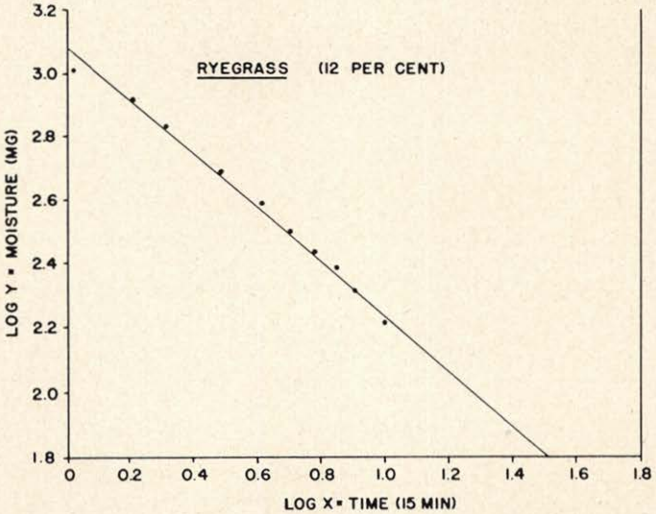

Figure 7.—Linear drying curve for ryegrass seed whose original moisture content was 12 percent.

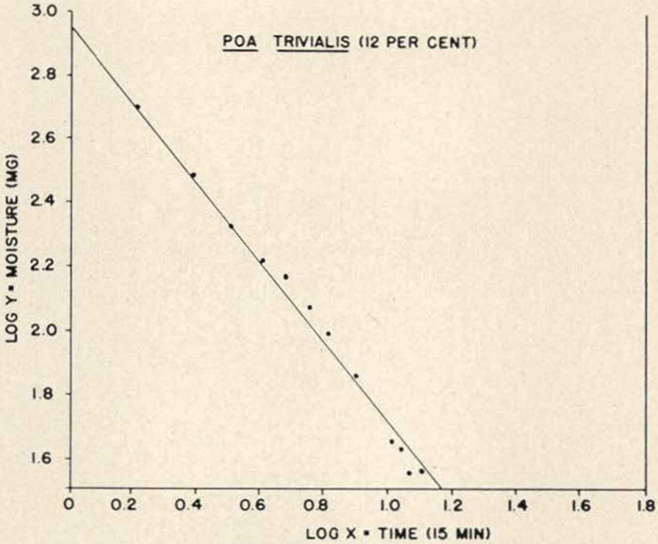

Figure 8.—Linear drying curve for rough stalk bluegrass seed whose original moisture content was 12 percent.

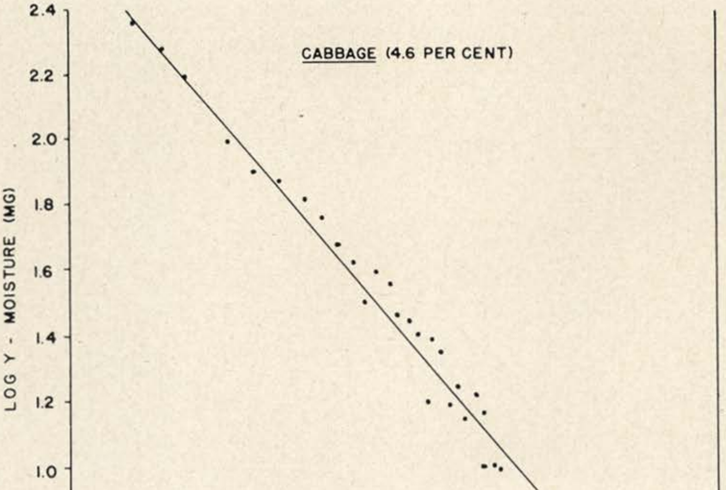

Figure 9.—Linear drying curve for cabbage seed whose original moisture content was 4.6 percent.

The seed was weighed out to an accuracy of 0.01 gram and placed in a container which could be sealed tightly during the conditioning period. The water was measured gravimetrically and added to the seed as quickly as possible to prevent loss by evaporation. Finally, the container was sealed and rotated to distribute the moisture evenly throughout the seed. Where the quantity of water added became significant, the seed tended to stick to the sides of the container, but this condition did not appear to cause any difficulties as the moisture soon diffused.

Experience showed that seed samples could be conditioned more quickly and uniformly if the batches did not exceed 50 grams in weight, and diffusion of the moisture appeared to be complete within 5 days. All operations relative to the preparation of the samples and moisture testing of the seed were carried out as rapidly as possible because small seeds seemed to lose and absorb measureable amounts of moisture in a matter of seconds.

The following 6 species were used in the remainder of this study:

1) Kentucky bluegrass (*Poa pratensis*)
2) Bermudagrass (*Cynodon dactylon*)
3) Highland bentgrass (*Agrostis tenuis*)
4) Creeping red fescue (*Festuca rubra*)
5) Perennial ryegrass (*Lolium perenne*)
6) White Dutch clover (*Trifolium repens*)

Sample series were prepared for each species in the manner explained above to encompass a moisture range from 5 to 15 percent, and, as closely as the technique permitted, in increments of 1 percent. For the purpose of establishing drying curves all test samples were weighed out to an accuracy of 1 milligram on an analytical balance. (When this method is used on a practical basis to predict moisture level, weighings needs only be made to 0.01 gram.) A sample weight of 10 grams was selected because it appeared to be an adequate quantity of small seed for a representative sample and this amount facilitated the calculation of moisture percentages. Three replicates of each moisture level were used and members of the series were staggered at 20- to 30-minute intervals for placment in the oven to: 1) facilitate weighing operations, 2) prevent overloading the oven and 3) to eliminate the necessity of keeping the oven door open for prolonged periods while transferring samples.

The seed was spread out in an even layer in 70-mm aluminum dishes and promptly covered until the samples were placed in the air-oven. The oven was maintained at a temperature of 101-103° C throughout the experiments. Although the oven temperature drops noticeably with the introduction of even five or six samples, recovery seems to be rapid enough so that, for all practical purposes, the temperature is uniform.

The importance of selecting an oven of the proper design cannot be overemphasized. The only type of air-oven found suitable for these experiments was one which had the following features: 1) heating elements enclosed within the walls and 2) a limiting thermostat to prevent overheating. Results obtained with ovens having other design specifications were unsatisfactory.

For purposes of statistical analysis two weighings were made, at 2 hours and at 24 hours. Prior to all weighing operations samples were cooled for 10 minutes in a glass desiccator over silica gel.

The percent of moisture loss after 2 hours in the air-oven was plotted along the ordinate against the actual (24-hour) moisture percentage. (See Fig. 10.) A graphical representation of the white clover data is included in the body of the report to facilitate discussion of the results. Curves and statistical data for all species investigated commence on page 12. An examination of Fig. 10 indicates the linear relation which occurred between the 2-hour and 24-hour drying times. This was extremely fortunate since it permitted the expression of this relation in the form of a simple linear regression and such data can be analyzed with comparatively simple statistical techniques. The general formula for a linear regression (3) is expressed as follows:

$$Y = \bar{y} + (Sxy \,/\, S\,x^2)\ (X - \bar{x})$$

For the specific example under discussion, white clover, a statistical analysis of the data develops the following relation:

$$Y = 1.48 + 1.03X$$

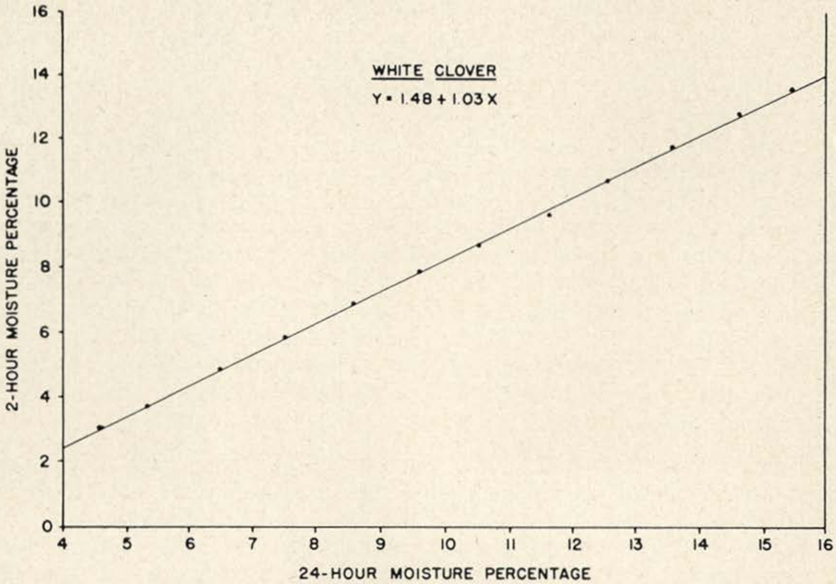

Figure 10.—Plot of 2-hour moisture percentage against 24-hour moisture percentage for white clover.

By substituting the percent of moisture loss obtained at the end of the 2-hour drying period, the actual moisture content can be computed. The sample moisture also can be obtained by using the curves.

Discussion

In order to test the accuracy and reliability of the derived formulae, 2-hour moisture determinations were made on several samples obtained from the Asgrow Research Center (Twin Falls, Idaho). The predicted moisture level was compared with routine 24-hour check and the results are summarized below:

Table 1.—Comparison of 2- and 24-hour moisture tests

Lot No.	Kind	24-hour test (percent)	2-hour test (percent)	Differential (percent)
19300	Merion bluegrass	8.4	8.2	-0.2
19302-1	" "	7.7	7.7	0
35384-1	" "	10.4	10.4	0
35384-2	" "	10.2	10.1	-0.1
35386	" "	10.8	10.7	-0.1
35392-1	" "	9.5	9.2	-0.3
35392-2	" "	10.4	10.3	-0.1
35397	" "	8.5	8.3	-0.2
35928	" "	10.7	10.7	0
35940	" "	10.7	10.7	0
15702	Kentucky bluegrass	11.1	11.0	-0.1
353918	*Poa trivialis*	10.7	10.7	0
35358	Creeping red fescue	10.9	10.5	-0.4
38575	Creeping red fescue	14.4	14.3	-0.1

It will be noted that in no instance did the discrepancy between the two tests exceed 0.4 percent, and in most cases the variation was significantly less. That the differential appeared negative in all instances can be explained by the fact that all 14 samples were placed in the oven simultaneously. This represents a rather heavy load and the oven recovered somewhat more slowly than when, for example, only 6 or 8 samples were inserted. Consequently, the samples did not dry quite as rapidly. The above data bore out the observation that a heavy load in the air-oven does not seriously affect the accuracy of the results.

From the data which were collected it appears that the results obtained with the air-oven method of quick moisture determination are more reliable and accurate than those attainable by any other method or instrumentation. This adaptation will provide seedsmen with a quick, convenient and accurate method for determining the moisture level of seed being processed for special packaging.

Table 2.—Statistical analysis of data.

KENTUCKY BLUEGRASS

2-Hour %	Actual %	Deviations from Mean		Squares of deviations	Products of
X	Y	X	Y	X^2	deviations
7.55	8.35	-3.26	-3.24	10.6276	10.5624
7.60	8.41	-3.21	-3.18	10.3041	10.2075
7.53	8.36	-3.28	-3.23	10.7584	10.5944
8.02	8.84	-2.79	-2.75	7.7841	7.6725
8.07	8.86	-2.74	-2.73	7.5076	7.4802
8.07	8.82	-2.74	-2.77	7.5076	7.5898
8.95	9.71	-1.86	-1.88	3.4596	3.4965
8.94	9.67	-1.87	-1.92	3.4969	3.5904
8.95	9.67	-1.86	-1.92	3.4596	3.5712
9.60	10.63	-1.21	-0.91	1 4641	1.1011
9.67	10.72	-1.14	-0.87	1.2996	0.9984
9.65	10.63	-1.16	-0.96	1.3456	1.1136
11.00	11.93	0.19	0.34	0.0361	0.0646
11.02	11.95	0.21	0.36	0.0441	0.0756
10.97	11.94	0.16	0.35	0.0256	0.0560
11.98	12.57	1.16	0.98	1.3456	1.1368
12.07	12.62	1.26	1.03	1.5876	1.2978
12.05	12.57	1.24	0.98	1.5376	1.2152
12.65	13.41	1.84	1.82	3.3856	3.3488
12.68	13.57	1.87	1.98	3.4969	3.7026
12.84	13.44	2.03	1.85	4.1209	3.7758
14.09	14.78	3.28	3.19	10.7584	10.4632
13.83	14.56	3.02	2.97	9.1204	8.9694
13.69	14.41	2.88	2.82	8.2944	8.1261
14.57	15.17	3.76	3.58	14.1376	13.4608
15.09	15.72	4.28	4.13	18.3184	17.6746
Sum 281.11	301.36	0	0	145.1540	141.3459
Mean 10.812	11.59				

$$\hat{Y} = \overline{y} + \frac{Sxy}{Sx^2} (X - \overline{x}) = 11.591 + \frac{141.3459}{145.1540} (X - 10.812)$$

$$= 11.591 + .9738 (X - 10.812) = 1.03 + .98X$$

NOTE—For the steps involved in the derivation of seed-moisture see Appendix, page 24.

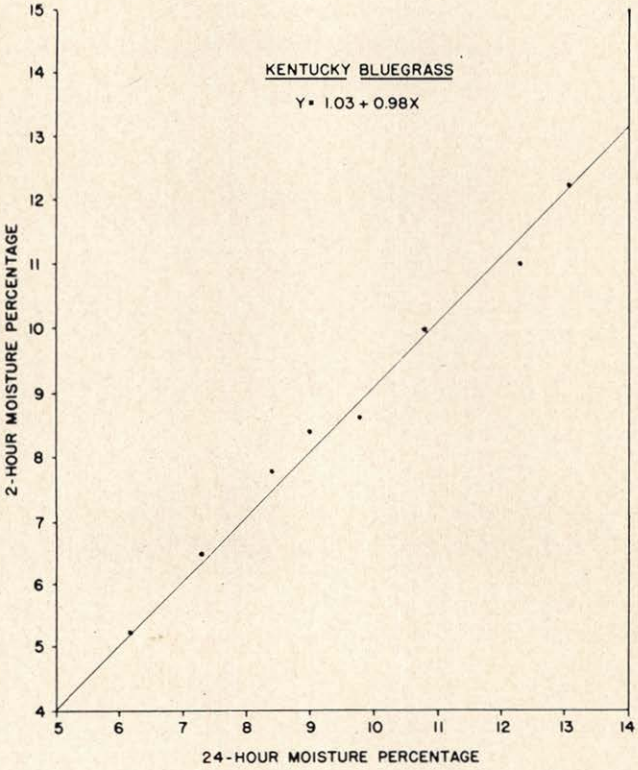

Figure 11.—Plot of 2-hour moisture percentage against 24-hour moisture percentage for Kentucky bluegrass.

Table 3.—Statistical analysis of data.

BERMUDAGRASS

2-hour %	Actual %	Deviations from Mean		Squares of deviations	Products of
X	Y	X	Y	X^2	deviations
5.63	7.24	-3.43	-3.56	11.765	12.211
5.57	7.30	-3.49	-3.50	12.180	12.215
5.47	7.28	-3.59	-3.52	12.888	12.637
6.23	8.09	-2.83	-2.71	8.009	7.669
6.27	8.07	-2.79	-2.73	7.784	7.617
6.50	8.14	-2.56	-2.66	6.554	6.810
7.06	8.96	-2.00	-1.84	4.000	3.680
7.09	8.96	-1.97	-1.84	3.881	3.625
7.13	8.91	-1.93	-1.89	3.725	3.648
8.13	9.91	-0.93	-0.89	0.865	0.828
8.18	9.96	-0.88	-0.84	0.774	0.739
8.24	10.01	-0.82	-0.79	0.672	0.648
9.23	11.06	0.17	0.26	0.029	0.044
9.22	10.99	0.16	0.19	0.026	0.030
9.20	10.92	0.14	0.12	0.020	0.017
10.14	11.86	1.08	1.06	1.166	1.145
10.03	11.83	0.97	1.03	0.941	0.999
10.09	11.85	1.03	1.05	1.061	1.082
11.02	12.77	1.96	1.97	3.842	3.861
11.04	12.76	1.98	1.96	3.920	3.881
11.07	12.82	2.01	2.02	4.040	4.060
12.20	13.87	3.14	3.07	9.860	9.640
11.71	13.31	2.65	2.51	7.023	6.652
12.92	14.55	3.86	3.75	14.900	14.475
12.96	14.60	3.90	3.80	15.210	14.820
13.22	14.85	4.16	4.05	17.306	16.848
Sum 235.55	280.87	0	0	152.441	149.881
Mean 9.06	10.80				

$$\hat{Y} = \overline{y} + \frac{Sxy}{Sx^2}(X - \overline{x}) = 10.80 + \frac{149.881}{152.441}(X - 9.06)$$

$$= 10.80 + 0.98X - 8.90 = 0.98x + 1.90$$

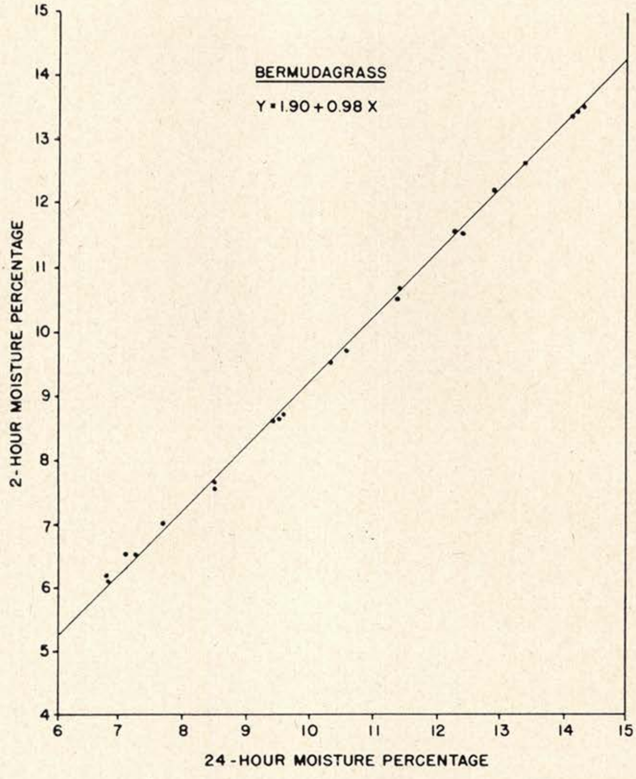

Figure 12.—Plot of 2-hour moisture percentage against 24-hour moisture percentage for bermudagrass.

Table 4.—Statistical analysis of data.

BENTGRASS

2-hour %	Actual %	Deviations from Mean		Squares of deviations	Products of
X	Y	X	Y	X^2	deviations
5.25	5.64	-4.985	-5.053	24.850	25.189
5.20	5.59	-5.035	-5.103	25.351	25.694
5.11	5.57	-5.125	-5.123	26.266	26.255
5.67	6.05	-4.565	-4.643	20.839	21.195
5.61	6.04	-4.625	-4.653	21.391	21.520
5.63	6.00	-4.605	-4.693	21.206	21.611
6.58	6.91	-3.655	-3.783	13.359	13.827
6.63	6.98	-3.605	-3.713	12.966	13.385
6.57	6.95	-3.665	-3.743	13.432	13.718
7.52	8.04	-2.715	-2.653	7.371	7.203
7.55	8.04	-2.685	-2.653	7.209	7.123
7.46	7.97	-2.755	-2.723	7.700	7.502
8.30	8.87	-1.935	-1.823	3.744	3.528
8.32	8.83	-1.915	-1.863	3.667	3.568
8.28	8.84	-1.955	-1.853	3.822	3.623
9.31	9.94	-0.925	-0.753	0.855	0.697
9.23	9.92	-1.005	-0.773	1.010	0.777
9.32	9.90	-0.915	-0.793	0.837	0.726
9.29	9.88	-0.945	-0.813	0.893	0.768
9.23	9.84	-1.005	-0.853	1.010	0.857
9.13	9.88	-1.105	-0.813	1.221	0.898
10.09	10.70	-0.145	0.007	0.021	0.001
9.97	10.80	-0.265	0.107	0.070	0.028
9.92	10.71	-0.315	0.017	0.099	0.005
10.23	10.70	-0.005	0.007	....	....
10.24	10.80	0.005	0.107	....	....
10.28	10.80	0.045	0.107	0.002	0.005
11.51	11.78	1.275	1.087	1.626	1.386
11.41	11.79	1.175	1.097	1.381	1.289
11.51	11.88	1.275	1.187	1.626	1.513
10.92	11.40	0.685	0.707	0.469	0.484
10.84	11.46	0.605	0.767	0.366	0.464
10.85	11.43	0.615	0.737	0.378	0.453
11.95	12.50	1.715	1.807	2.941	3.099
12.03	12.43	1.795	1.737	3.222	3.118
12.57	12.43	2.335	2.037	5.452	4.756
12.51	12.76	2.275	2.067	5.176	4.680
12.74	12.95	2.505	2.257	6.275	5.654
13.52	13.83	3.285	3.137	10.791	10.305
13.47	13.88	3.235	3.187	10.465	10.310
13.48	13.85	3.245	3.157	10.530	10.244
13.32	13.75	3.085	3.057	9.517	9.431
13.31	13.71	3.075	3.017	9.456	9.277
13.29	13.71	3.475	3.017	12.076	10.484
14.54	14.80	4.305	4.107	18.533	17.681
14.41	14.75	4.175	4.057	17.431	16.938
14.37	14.70	4.135	4.007	17.098	16.569
14.41	14.79	4.175	4.097	17.431	17.105
14.42	14.78	4.185	4.087	17.514	17.104
14.46	14.80	4.225	4.107	17.851	17.352
Sum 511.76	534.65	0	0	416.826	399.399
Mean 10.235	10.693				

$$\hat{Y} = \bar{y} + \frac{Sxy}{Sx^2}(X - \bar{x}) = 10.693 + \frac{399.399}{416.826}(X - 10.235)$$

$$= 10.693 + 0.958\ (X - 10.235) = 0.888 + .958x$$

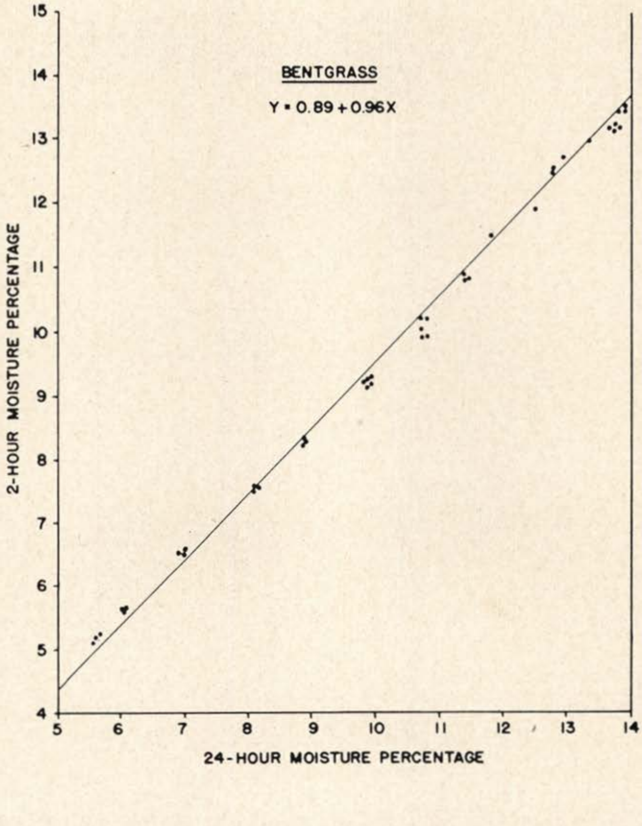

Figure 13.—Plot of 2-hour moisture percentage against 24-hour moisture percentage for bentgrass.

Figure 5.—Statistical analysis of data.

RYEGRASS

2-hour % X	Actual % Y	Deviations from Mean X	Y	Squares of deviations X^2	Products of deviations
4.48	5.99	-4.22	-4.31	17.8084	18.1882
4.39	5.95	-4.31	-4.35	18.5761	18.7485
4.55	5.89	-4.15	-4.41	17.2225	18.3015
4.90	6.35	-3.90	-3.95	15.2100	15.4050
4.76	6.29	-3.94	-4.01	15.5236	15.7994
4.73	6.32	-3.97	-3.98	15.7609	15.8006
5.68	7.36	-3.02	-2.94	9.1204	8.8788
5.63	7.29	-3.07	-3.01	9.4249	9.2407
5.76	7.43	-2.94	-2.87	8.6436	8.4378
6.72	8.34	-1.98	-1.96	3.9204	3.8808
6.68	8.31	-2.07	-1.99	4.2849	4.1193
6.76	8.30	-1.94	-2.00	3.7636	3.8800
7.55	9.37	-1.15	-0.93	1.3225	1.0695
7.59	9.30	-1.11	-1.00	1.2321	1.1100
7.57	9.19	-1.13	-1.11	1.2769	1.2543
8.50	10.19	-0.20	-0.11	0.0400	0.0220
8.67	10.28	-0.03	-0.02	0.0009	0.0006
8.58	10.25	-0.12	-0.05	0.1440	0.0060
9.62	11.24	0.92	0.94	0.8464	0.8648
9.70	11.29	1.00	0.99	1.0000	0.9900
9.66	11.19	0.96	0.89	.9216	0.8544
10.91	12.26	2.21	1.96	4.8841	4.3316
10.57	12.14	1.87	1.84	3.4969	3.4408
10.68	12.13	1.98	1.83	3.9204	3.6234
11.30	12.94	2.60	2.64	6.7600	6.8040
11.44	13.11	2.74	2.81	7.5076	7.6994
11.55	13.17	2.85	2.87	8.1225	8.1795
12.43	14.10	3.73	3.80	13.9129	14.1740
12.41	14.03	3.71	3.73	13.7641	13.8383
12.69	14.27	3.99	3.97	15.9201	15.8403
13.68	15.28	4.98	4.98	24.8004	24.8004
13.57	15.13	4.87	4.83	23.7169	23.5221
13.66	15.17	4.96	4.87	24.6016	24.1552
Sum 287.32	339.85	0	0	297.4572	297.3212
Mean 8.7036	10.2984				

$$\hat{Y} = \overline{y} + \frac{Sxy}{Sx^2}(X - \overline{x}) = 10.2984 + \frac{297.3212}{297.4572}(X - 8.7036)$$

$$10.2984 + 0.9995X - 8.6997 = X + 1.59$$

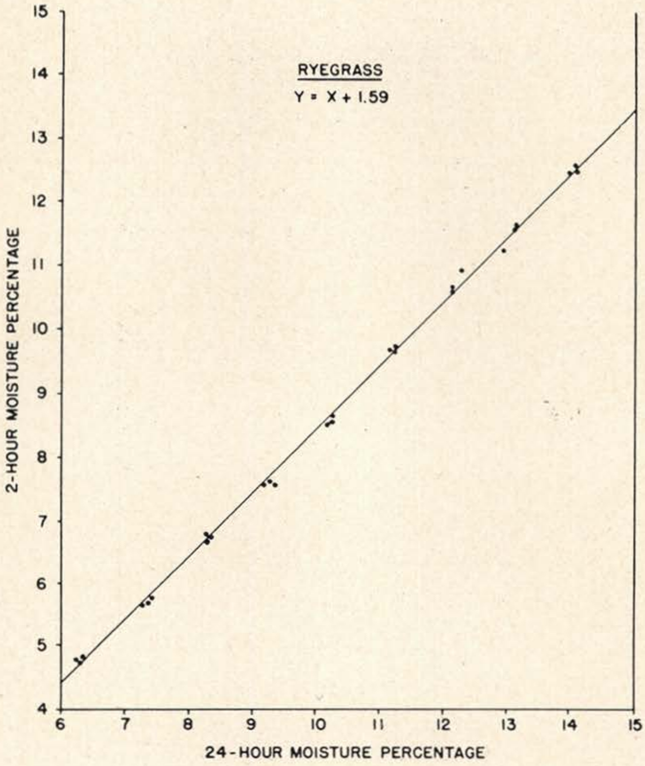

Figure 14.—Plot of 2-hour moisture percentage against 24-hour moisture percentage for ryegrass.

Table 6.—Statistical analysis of data.

CREEPING RED FESCUE

	2-hour %	Actual %	Deviations from Mean		Squares of deviations	Products of
	X	Y	X	Y	X^2	deviations
	5.88	7.05	-4.35	-4.43	18.9225	19.2705
	6.81	8.12	-3.42	-3.36	11.6964	11.4912
	7.76	9.12	-2.47	-2.36	6.1009	5.8292
	8.87	10.03	-1.36	-1.45	1.8496	1.9720
	9.85	11.04	0.38	-0.44	.1444	0.1672
	10.55	11.62	.32	0.14	.1024	0.0448
	11.61	12.92	1.38	1.44	1.9044	1.9872
	12.76	13.97	2.53	2.49	6.4009	6.2997
	13.51	14.91	3.28	3.43	10.7584	11.2504
	14.72	16.07	4.49	4.59	20.1601	20.6091
Sum	102.32	114.85	0	0	78.0400	78.9213
Mean	10.232	11.485				

$$\hat{Y} = \overline{Y} + \frac{Sxy}{Sx^2}(X - \overline{x}) = 11.485 + \frac{78.9213}{78.0400}(X - 10.232)$$

$$= 11.485 + 1.0113\ (X - 10.232) = 1.137 + 1.011X$$

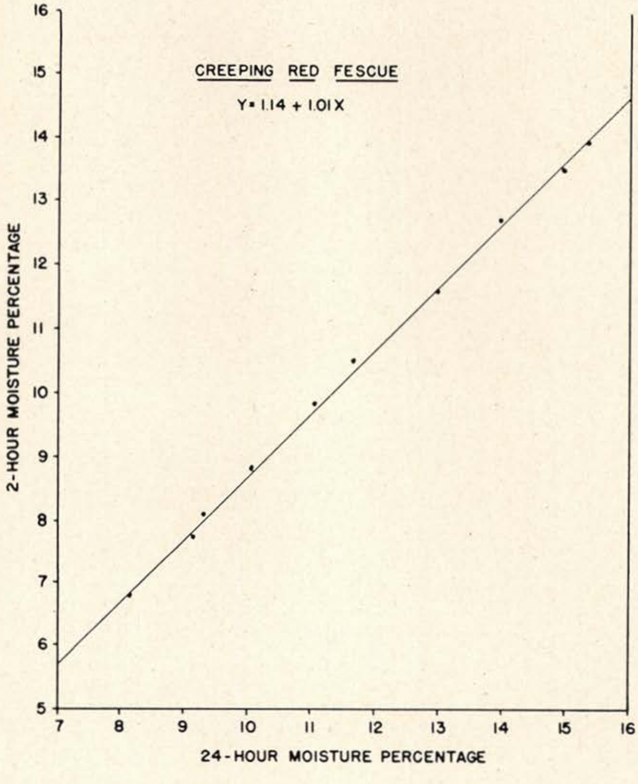

Figure 15.—Plot of 2-hour moisture percentage against 24-hour moisture percentage for creeping red fescue.

Table 7.—Statistical analysis of data.

WHITE CLOVER

2-hour %	Actual %	Deviations from Mean		Squares of deviations	Products of
X	Y	X	Y	X^2	deviations
3.04	4.54	-5.28	-5.51	27.56	28.93
3.03	4.57	-5.29	-5.48	27.67	28.83
3.05	4.60	-5.27	-5.45	27.48	28.56
3.80	5.30	-4.52	-4.75	20.16	21.33
3.90	5.38	-4.42	-4.67	19.27	20.50
3.88	5.33	-4.44	-4.72	19.45	20.82
4.85	6.51	-3.47	-3.54	11.83	12.18
4.88	6.49	-3.47	-3.56	11.63	12.14
4.90	6.53	-3.42	-3.52	11.49	11.93
5.80	7.46	-2.52	-2.59	6.20	6.45
5.83	7.54	-2.49	-2.51	6.05	6.17
5.90	7.59	-2.42	-2.46	5.71	5.88
6.92	8.58	-1.40	-1.47	1.88	2.01
6.87	8.55	-1.45	-1.50	2.02	2.13
6.99	8.58	-1.33	-1.47	1.69	1.91
7.88	9.54	-0.44	-0.51	0.17	0.21
7.86	9.52	-0.46	-0.53	0.18	0.23
7.89	9.61	-0.43	-0.44	0.16	0.28
8.61	10.60	0.29	0.55	0.10	0.18
8.61	10.47	0.29	0.42	0.10	0.13
8.75	10.63	0.43	0.58	0.21	0.27
9.52	11.52	1.20	1.47	1.51	1.81
9.70	11.69	1.38	1.64	1.99	2.31
9.83	11.82	1.51	1.77	2.37	2.73
10.68	12.56	2.36	2.51	5.71	6.09
10.69	12.58	2.37	2.53	5.76	6.07
10.71	12.59	2.39	2.54	5.86	6.15
11.76	13.60	3.44	3.55	12.04	12.32
11.68	13.51	3.36	3.46	11.49	11.73
11.76	13.61	3.44	3.56	12.04	12.35
12.87	14.62	4.55	4.57	20.98	20.93
12.70	14.48	4.38	4.43	19.45	19.54
12.97	14.77	4.65	4.72	21.90	22.09
13.70	15.46	5.38	5.41	29.27	29.27
13.69	15.45	5.37	5.40	29.16	29.16
13.97	15.83	5.65	5.78	32.26	32.83
Sum 299.47	362.01	0	0	412.80	426.26
Mean 8.32	10.05				

$$\hat{Y} = \bar{y} + \frac{Sxy}{Sx^2}(X - \bar{x}) = 10.05 + \frac{426.26}{412.80}(X - 8.32)$$

$$= 10.05 + 1.03\,(X - 8.32) = 1.48 + 1.03X$$

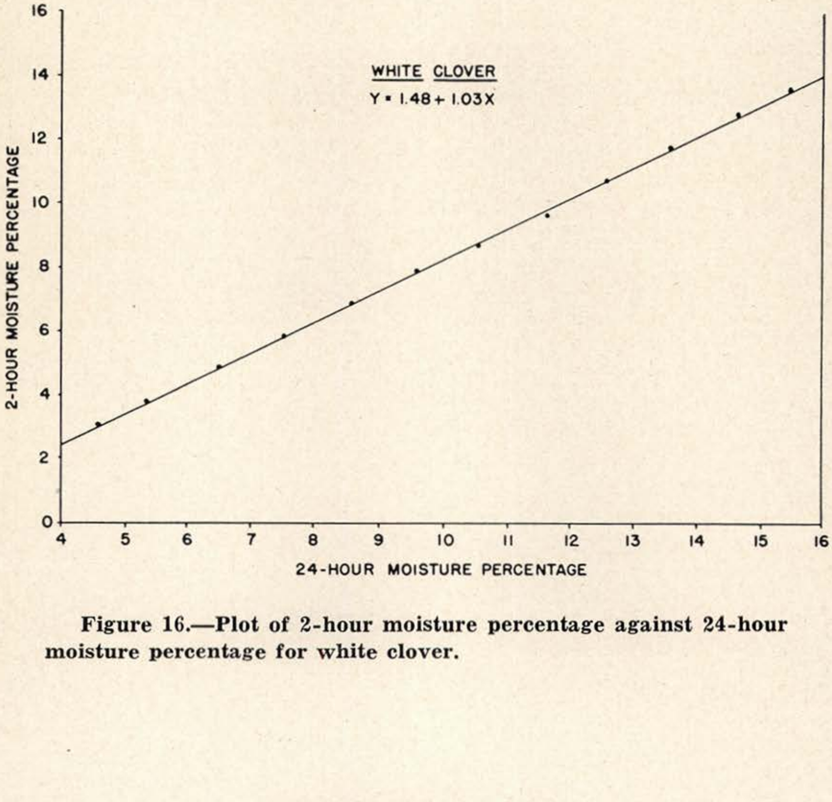

Figure 16.—Plot of 2-hour moisture percentage against 24-hour moisture percentage for white clover.

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2. Proceedings of the International Seed Testing Association, Copenhagen, Denmark. 1956. 36.

3. Snedecor, G. W. Statistical Methods. Iowa State College Press. 1950. 103-113.

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5. Turner, J. E. Instructions for the Use of the "Cenco Moisture Balance" for the Determination of the Moisture Content of Seed Lots Being Processed for Packaging in Hermetically-Sealed Containers. Project P-15. Asgrow Research Center, Twin Falls, Idaho. 1954.

Appendix

DERIVATION OF SEED-MOISTURE CONDITIONING

Step 1) Moisture ratio = wt. of water driven off / original wt. of sample.

Step 2) Original wt. = dry wt. + wt. of water driven off.

Step 3) Let d = dry wt. of sample
w = wt. of water in original sample
m = desired moisture ratio
V = total wt. of moisture (water) in conditioned sample, i.e., wt. of moisture added + wt. of water in original sample
V′ = wt. of moisture to be added

Step 4) Express the equation in step (1) in terms of the symbols presented in step (3):

$$m = V/d + V$$

Step 5) Solve for V:

$$m\ (d + V) = V$$
$$md + mV = V$$
$$V - mV = md$$
$$V\ (1 - m) = md$$
$$V = (md/1\text{-}m)$$

Step 6) Subtract the quantity of water present in the original sample:

$$V' = V - w, \text{ or}$$
$$= (md/1-m) - w$$