Objective Methods In Forecasting Components of Corn Yield

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As part of its research program during the last 4 years, the Agricultural Estimates Division, AMS, has conducted extensive studies on objective yield forecasting methods for several important field crops. Some results of these studies on cotton in the South and on soybeans in the North Central States have been reported in earlier issues. Results of the studies on corn reported in this paper are based on data for 4 years in the South and for 2 years in the North Central States, together with data from a project that has been conducted in cooperation with Iowa State College for several years.

This report summarizes results obtained from objective corn yield forecasting studies conducted in the South and in the North Central States. The data were collected in probability samples of fields in the two regions for a 4-year period—1954–57.

The 1954 sample consisted of 200 fields in 10 Southern States. This was increased to 400 fields in 1955 and to 600 in 1956 and 1957. In 1956, 600 fields in 11 North Central States, Kentucky, and Virginia were added to the program. These were also covered in 1957.

The statistical reliability of the data can be appraised in a general way from the field-to-field sampling variation of ripe ear weight in the sample plots used for plant observations. That variability is about 80 percent on a per field basis. This means that the sampling error in a per field average derived from a sample, even as small as 200 fields, should be only $80/\sqrt{200}$, or less than 6 percent. Of course, the sampling error in the observed data is only one component of the possible error in a yield forecast derived from these data.

Although the same general principles apply in both regions of the country, the practical problem of forecasting yields as of any given forecast date is somewhat different in the South from that in the North Central area, because the crop is in a more advanced stage of development in most of the South. The development of objective yield forecasting formulas that apply to official crop forecast dates must rest upon observable plant characteristics and sufficient knowledge of the fruiting behavior of the plant so that plant characteristics observed on any date can be translated into an indication of yield. The studies reported here relate to the forecast dates August 1, September 1, and October 1. Field observations, in each instance, were taken during the previous week.

Early in the season, ears or ear shoots that may already be present can be counted in sample plots in sample fields. But when counts are made before all "ears" have had time to emerge, other observable plant characteristics must be used.

As the crop approaches maturity, some ears have attained their maximum length so that the average size of the ears that will be harvested can be ascertained by direct measurement. The average quantity of ripe grain that will be produced per ear is closely related to average length of ear at maturity. Maximum ear length is attained before the grain is ripe. In order to ascertain whether an ear has reached its maximum length on a given forecast date, the stage of maturity of the ear must be considered. Numerous studies on corn, including those made in the present program, show that ears in the milk stage have reached their maximum length. Consequently, measurements of ears in the milk stage were used to forecast the average size of ear at harvesttime.

When corn is already ripe on a forecast date, sample ears can be harvested, weighed, and subjected to laboratory analysis to compute the average weight of grain per ear at a standard moisture content.

As of August 1, all "ears" have not yet appeared in the two regions as a whole. An August 1 yield forecast must first provide a forecast of the number of ears that will be present at harvesttime. It is also necessary to forecast the quantity of grain that will be produced per ear.

By September 1, all ears that have a chance of reaching maturity are present and most are well developed. But in many places even corn that looks ripe has not yet laid down all of the dry matter in the grain. As a kernel of grain ripens, the weight of the total dry matter in the kernel increases. This weight levels off at a maximum when the moisture content of the kernel reaches 30 percent.

By October 1, practically all ears have attained the dry-matter content of grain that can be expected at harvest, except in the very latest maturing fields. In parts of the Northern States, such as Minnesota, Wisconsin, and Michigan, the accumulation of dry matter may be stopped by killing frost before the full yield potential is realized. If frost occurs late enough, the ears may still be harvested for grain, but the grain will be lighter than if development had not been arrested. If frost occurs earlier, the ears may be so immature that the crop must be diverted to uses other than harvest as grain. If this occurs, the contribution of these ears to the total yield of grain may be zero. This is customarily described as the "soft-corn" problem.

Pertinent Relationships for the August 1 Yield Forecast

The forecast of number of ears to be produced is considered first. An observable ear or ear shoot is defined as one that has already developed, at least to the stage at which some silks are protruding from the husk. As of August 1, practically all ears or ear shoots that have a chance of maturing are already present on the plants in most of the South. In a few borderline Southern States, and in the North Central States, the ears and ear shoots present are less than the number that will be found at maturity. It is these areas that require our attention first.

The plant observations are made in two double 15-foot row sections in each sample field. If some of the ears in these small plots have already reached the milk stage, there is little chance of any additional ears appearing later. The ear count represents all ears that will be formed. But if no ears have yet reached the milk stage, the total number of ears to be formed must be forecast. Two methods of making this forecast are currently under investigation.

TABLE 1.—*Number of mature ears produced per 60 feet of row, in relation to August 1 stalk count*

August 1 stalk count	Mature ears produced	August 1 stalk count	Mature ears produced
10	10	45	45
15	16	50	50
20	21	55	55
25	26	60	59
30	31	65	64
35	36	70	68
40	41		

The first approach involves counting the stalks in the measured plots and assuming a constant number of ears per stalk from year to year. The second approach assumes a fixed linear relationship between the fraction of stalks with ears on August 1 and the ratio of ears already present to the total number of mature ears that will be produced. No conclusion has been reached as to which of these two approaches is the better. They have given about the same results and the same relationships appear to hold in both the South and the North Central States. The second procedure would be preferable if the number of ears produced per stalk were subject to greater variation from year to year than experience to date indicates.

Data collected during the last several years show that the number of mature ears produced in 60 feet of a row is related to the August 1 stalk count, as shown in table 1. The data in this and subsequent tables are based on free-hand charts drawn on scatter diagrams in which the original data and group averages were plotted.

On the average, about 1.05 mature ears are produced in the South for each stalk counted on August 1. In the North Central States, where yields are higher, the average is 0.98. This difference is not inconsistent with the relationship in table 1, which holds for both regions. When the average stalk count is low, the average number of ears per stalk is greater than unity, and vice versa. The average stalk count is lower in the South than in the North Central region.

Stalks with 2 ears occur more frequently in the South. But field-to-field variation in the number of ears produced per stalk is generally greater. The greater frequency of 2-ear stalks in the South

TABLE 2.—*Ratio of "ears" counted August 1 to mature ears produced, in relation to fraction of stalks with "ears" on August 1, North Central States, and Kentucky and Virginia*

Stalks with "ears", August 1	Ratio of August 1 "ear" count to mature ears produced	Stalks with "ears", August 1	Ratio of August 1 "ear" count to mature ears produced
Percent		*Percent*	
5	10	60	87
10	23	70	100
20	36	80	114
30	49	90	127
40	62	100	140
50	74		

is largely nullified by fields that produce less than 1 ear per stalk.

When the fraction of stalks that have ears or ear shoots on August 1 is used to forecast the number of mature ears that will be produced, relationships in the South differ somewhat from those in the North Central region. The ratio of ears and ear shoots counted on August 1 in the South to mature ears produced is about 1.4 times the fraction of stalks having ears or ear shoots on August 1. In the North Central States, the relationship is as shown in table 2. Kentucky and Virginia were included with the North Central States, rather than with the Southern States. The characteristics of the crop in these two States on each forecast date resemble the characteristics of the crop in the North Central region more closely than those of the crop in the Southern region.

Whenever the August 1 percentage of stalks with ears is low and ears have emerged in only a few fields, it seems preferable to assume a fixed number of ears per stalk (1.05 in the South or 0.98 in the North Central States), rather than to adjust the observed August 1 "ear" count as shown in table 2. In practice, it is desirable to consider fields in which no ears have yet emerged separately from those in which some ears have emerged. If there are fewer than 20 sample fields in the second group, table 2 fails to give a good indication of fruiting potential, even for the fields in that group.

It is preferable to apply the assumed average number of ears per stalk to the fields in both groups. But if ears have emerged in 20 or more sample fields, the relationship in table 2 can be applied to data from this group to compute a current forecast of the average number of ears to be produced per stalk. This estimate can then be applied to the average stalk count for all fields in both groups.

The weight of grain produced per ear did not vary much from year to year during the period in which these studies were conducted. But a method of forecasting this weight early in the season is desirable. In much of the South, most ears have reached the milk stage, and their maximum length, by August 1. The length of the entire ear, or of the part of the ear that is covered by kernels, can then be used to predict the average weight of grain per ear at maturity. It is more convenient to measure the length of the entire cob over the husk. This procedure also avoids damage to the ear.

For ears that have reached their full length but are not ripe, the relationship between length of ear, measured over the husk, and weight of grain produced per ear is:

$$Y=0.0854X-0.304 \quad (1)$$

In this equation, X is the total length of cob in inches, measured over the husk, and Y is the weight of grain produced in pounds, adjusted to 15.5 percent moisture content.

For ears that are already mature (maximum dry matter attained), the equation becomes:

$$Y=0.0886X-0.310 \quad (2)$$

The difference in the two equations arises from the fact that ears shrink slightly as they ripen and become drier.

These relationships appear to be the same in the two regions of the country, and they are constant from year to year. But in a few Southern States and in most North Central States, ears have not yet reached their full length by August 1. In such instances, the weight of the grain must be predicted in some other way. There appears to be a relationship between the number of mature ears produced in 60 feet of row and weight of grain.

As the planting system in any area is relatively unchanged from one year to another, variations in ear counts reflect differences in growing conditions. Favorable growing conditions are conducive to good stands and the formation of large numbers of ears. These conditions are also conducive to good development of the ears. This

TABLE 3.—*Relation of weight of grain per 60 feet of row to number of ears with grain*

Ears with grain per 60 feet of row	Weight of grain at 15.5 percent moisture	
	North Central States	Southern States
Number	*Pounds*	*Pounds*
5	1.0	0.8
10	2.0	1.6
15	3.7	3.0
20	5.7	4.5
25	8.0	6.4
30	10.5	8.5
35	13.2	11.0
40	16.0	13.7
45	18.5	16.4
50	21.5	19.1
55	25.0	----------
60	28.2	----------
65	31.5	----------
70	34.8	----------

view is consistent with the behavior of other crops that have been studied in the research program on objective yield forecasting. The data in table 3 indicate that this is also true for corn.

As the number of mature ears expected can be forecast fairly well, this offers some chance of predicting the change in the quantity of grain to be produced per ear. The relationship is somewhat different in the North Central States (including Kentucky and Virginia) from that in the Southern region, as shown in table 3.

Table 3 could be used directly to forecast the weight of grain when the number of ears per 60 feet of row is known. But because the curve describing the relationship is at a different level in one location or State as compared with another, it is more accurate to use the table to indicate change from a previous year. If the number of mature ears per 60 feet of row and the weight of the grain are known for a previous year, the change in the weight of the grain associated with the change in the number of ears as indicated by table 3, can be applied to the grain weight for the previous year. This relationship has not yet been tested as extensively as those for other components of yield. But it is the only one that has been developed to date for forecasting the quantity of grain that will ultimately be produced by plants in such an immature stage of development.

Relationships for a September 1 Yield Forecast

By September 1 most of the ears that will produce grain are mature enough to be identified and counted. If a few fields have not reached the milk stage, the total number of mature ears expected can be predicted as for the August 1 forecast. But as a practical matter it is simpler, and just as satisfactory, to assume that the average number of ears per stalk-producing grain will be about the same for these fields as for the fields that are already more mature. The weight of the grain that will be produced can be estimated from the length of the cob, measured over the husk, as for the August 1 forecast.

A slightly more accurate indication can be obtained by considering only the length of the part of the cob that is covered by kernels. The average weight of grain per ear is related to this length by the equation:

$$X=0.0890X-0.215 \quad \text{----------} \quad (3)$$

As in equations (1) and (2), the weight per ear is in terms of pounds of grain at 15.5 percent moisture and the length of ear covered by kernels is measured in inches.

When fields are fully mature the sample ears can be weighed in the field, the shelled grain weighed in the laboratory, and moisture tests made. But even for such fields, ear-size measurements give an accurate weight indication much more quickly. In most States, the percentage of fields that have matured fully by September 1 is small. Even ears that look ripe may not have laid down all of the dry matter in the kernels.

The fraction of total dry matter already present in the kernels can be estimated from the ratio of dry kernel weight to wet kernel weight, as shown in table 4. This relationship is useful for forecasting the weight per ear at maturity or for adjusting grain weights when sample ears are harvested and weighed too early. It is also useful for estimating the reduction in yield caused by frost before ears reach full maturity. The data in the table are rounded average figures derived from laboratory studies at Iowa State College on a large number of sample ears from the North Central States during the last few years.

Table 4 gives the relationship between averages for large numbers of ears. Although any one ear for which the ratio of dry kernel weight to wet kernel weight is 70 percent has already laid down

all of its dry matter, any group of ears for which the average ratio is 70 percent must obviously include some ears for which the ratio is less than 70 percent. For this reason, the data in the table indicate a slightly different trend from one that would be observed in data for individual ears. But the trend shown in the table corresponds more closely to the way data are usually tabulated in practice.

Relationships for an October 1 Yield Forecast

By October 1 all dry kernel weight has been laid down in most southern fields. Weights of harvested sample ears or measurements of ear length give accurate indications of weight of grain per ear. In the North Central States, also most fields are fully mature. But in some of these States, the weight of grain per ear must often be estimated from ear-size measurements for half or more of the acreage. This estimate can be computed from the average amount of grain per inch observed in past years as reflected in equations (1), (2), and (3), or from the average amount of grain per inch observed in mature ears harvested currently.

A more accurate indication can be obtained by weighing sample ears and applying the relationship in table 4 to adjust the observed grain weight to a mature level. But if the production of dry matter is halted by a killing frost before the ears have a chance to reach maturity, an allowance must be made for the resulting reduction in yield. When the moisture content is known, table 4 can be used for this purpose.

TABLE 4.—*Relationship between ratio of dry kernel weight to wet kernel weight and fraction of total dry matter laid down*

Average ratio of dry kernel weight to wet kernel weight	Average fraction of total dry matter laid down	Average ratio of dry kernel weight to wet kernel weight	Average fraction of total dry matter laid down
Percent	*Percent*	*Percent*	*Percent*
10	5	50	70
20	15	60	85
30	30	70	95
40	50	80	100

Conclusion

Our discussion covers results obtained to date on the general problem of forecasting and measuring specific components of corn yield, in both the South and the North Central States, on August 1, September 1, and October 1. These results are now being applied on an experimental basis in the two regions. As experience accumulates, it is probable that the basic average relationships described in this report may need to be modified for groups of States, or possibly State by State, to make them apply more precisely to conditions existing in each individual State.

Procedures now being tested for making a yield forecast as of any forecast date can be summarized as follows:

1. If the crop is ready for harvest, count ears and apply the average weight of grain per ear, as derived from (a) harvesting sample ears and weighing the grain, or (b) measuring the length of sample ears and estimating the weight of the grain from the size of the mature ear.

2. If the crop is not ripe but ears have their maximum length (milk stage), count the ears and estimate the grain to be produced per ear from measured ear length.

3. If all ears are present but some have not reached maximum length, count the ears and forecast the average maximum length by (a) measuring ears that are in the milk stage, and/or apply table 3 to forecast ear size from the ear count.

4. If all ears are not yet present, forecast the total number to be formed (a) by applying an assumed average number of ears per stalk to the stalk count, or (b) by applying table 2 to get a current estimate of fruiting potential from fields that are already fruiting. Forecast ear size from the forecast of ear count.

5. In northern parts of some North Central States, the possibility of reduction in yield from frost must also be taken into account. Adjustment may be required for failure of ears to mature sufficiently to be harvested as grain, or for failure of the grain to reach its maximum dry weight even if it has matured sufficiently to be harvested as grain.