FORECASTING CROP YIELDS

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Some hold that historians tell us about the past, that economists tell us about the future, and that it is only the present that is confusing. The discussions of the seminar may substantiate this belief.

We have heard about the past -- weatherwise, crop production-wise, and research-wise. We can look forward to hearing about the future and what it holds for crop yields. That leaves us only to worry about what is happening at the present time. That task is generally left to the Statistical Reporting Service along with a handful of professional estimators and thousands of self-appointed prognosticators.

We can all agree that crop yields are the culmination of a wide variety of variables, most of which show varying degrees of relationship to one another -- some positive and some negative in terms of crop output. One of the most controversial variables is weather, but even here we can agree that crop yields are dependent upon the weather -- assuming weather in its broadest sense. Other variables that exert significant influence on yields are soil type, soil fertility, plant population, variety, insects, disease and cultural practices.

What is the interaction of these items with weather -- some of which have occurred during the growing season to date, some of which must still occur during the current growing season? These questions offer interesting thoughts for speculation. Researchers can and do isolate one or more of these items and present evidence of their impact on yield. One of the problems to date has been the rather wide variation in evidence. You are aware of the various opinions relative to the effect of weather on the recent sharp uptrend in yields for certain crops -- ranging from only minor effect to accounting for more than 80 percent of the increase. Similar differences are voiced relative to plant population, application of fertilizer, new varieties, etc. These are all interesting items for speculation and helpful in the evaluation of a given set of conditions in relation to yield, but how well do such opinions or results measure the combined effects of the many

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factors that result in the amount of product removed from a given acre? These opinions and research results do illustrate the luxury enjoyed by some in speculating about the cause and effect of yields. We in the Statistical Reporting Service seldom enjoy such luxury — ours is the role of being expected to know what is happening to yield month by month.

The Statistical Reporting Service has the responsibility for making (1) forecasts of crop production from current crop conditions during the growing season and (2) annual estimates of crop production. These are two separate and distinct functions. We use "estimate" to indicate a measure of accomplished fact, such as at harvest time or later; the term "forecast" is used to refer to expectations of what is likely to be accomplished at some time in the future.

It should be clearly understood that a forecast is a statement of the most likely magnitude of yield or production on the basis of known facts on a given date. This assumes weather conditions and damage from insects or other pests and disease during the remainder of the growing season to be about the same as the average of previous years when the reported condition on the given date was similar to the present reported condition. The yield potential of the current condition may be appraised accurately. However, if weather or other conditions between the date of the forecast and the time of harvest are not similar to those experienced in past seasons that have been used in the determinations, the actual yield may differ from the forecast. As the season progresses, the forecasts made at or just before harvest merge into estimates of accomplished fact.

Methods and procedures utilized in crop estimating have changed to reflect the needs of users of statistical data as well as adapting to the organizational changes of agriculture.

The general methods employed in estimating yield of field crops are based largely on the theory of sampling — selecting a limited number in the universe whose behavior is used to describe the behavior of the whole. The sampling procedures embrace both mail and enumerative survey methods. The aim is to maintain as much objectivity as possible in sample data. It would be desirable to place all surveys on a random sampling basis so that measures of reliability may be mathematically calculated. In practice, this is difficult. For the most part, samples consist of farmers who report voluntarily on operations for the farm they operate or the locality in which they farm. Locality data provided by the volunteer reporters are largely subjective — that is, reporters must exercise considerable judgment in arriving at the figures they report.
History of Crop Reporting

Assuming the role of the historian, I would like to devote a few moments to what has happened in crop reporting during the past 100 years. These historical developments have a direct bearing on where we are today.

The Department of Agriculture was established May 15, 1862. Its responsibilities included the collection and distribution of annual and current agricultural statistics.

The first Commissioner of Agriculture, Isaac Newton, announced that the first item on his agenda was "collecting, arranging, publishing and disseminating, for the benefit of the nation, statistical and other useful information in regard to agriculture in its widest acceptance." One of his first actions was to develop a corps of voluntary farm reporters who submitted reports that were used as a basis for estimating crops.

In early 1863, a Statistical Division was formed in USDA. The first chief statistician initiated a reporting program that consisted of a corps of voluntary reporters representing each county in the country who would be sent blank reporting forms to be returned by the 10th of each month in the growing season. These simple, easy-to-fill out forms asked for acreage of and prospects for different crops. The first monthly crop report was published in July 1863 based on replies from 2,000 farm correspondents. For this report, correspondents were asked (a) average amount of land sown compared with 1862 and (b) "appearance" of the crop at the date in tenths of average. Data published were the average of these reports for each state and for the nation. No estimates of actual acreage and production by states during the growing season were published until more than 40 years later.

In 1866, rather than "appearance" an estimate of "condition" of crops was asked, a term that has continued to the present. Because of the impossibility of averaging nonquantitative statements such as "excellent," "good," "fair," or "poor," a numerical scale was adopted, with 10 representing an "average" condition and lesser or greater numbers representing conditions poorer or better than "average." However, it soon became evident that farmers had difficulty in visualizing an average condition. This was demonstrated by the fact that over a period of years, the average of all reports of condition was somewhat less than 10. To get away from the use of "average," the concept of "normal" condition became the standard by which reporters were asked to rate condition of crops.
A normal condition is not an average condition, but a condition above average, giving promise of more than an average crop. Furthermore, a normal condition does not indicate a perfect crop, or a crop that is or promises to be the very largest in quantity that the area reported upon may be considered capable of producing. The normal indicates something less than this and thus comes between the average and the possible maximum. The normal can be described as a condition of perfect healthfulness, unimpaired by drought, hail, insects or other injurious agency, and with such growth and development as may be reasonably looked for under these favorable conditions.

The concept of what constitutes a "normal" condition of a crop obviously varies from one locality to another with difference in soil and climate. It also changes slowly, over time, in the same locality because of change in varieties, cultural practices and soil fertility. Shifts in the acreage distribution of a crop within a state, from acres of low yields to acres of high yields, may mean that the same reported condition will indicate a higher yield than it once did. A shift in the opposite direction may have the reverse effect. The relative constancy of the aggregate of all the individual reporters' ideas of normal condition has greatly enhanced its usefulness.

During these early years there was much concern about the reliability of estimates. Efforts were made to improve the data by increasing the number of correspondents. This began a period of transition in the method of making annual production estimates. Up to this time, estimates were based on reports by county reporters of the total crop production for the county as a percent of the previous year. Beginning about 1888, county indications were weighted to calculate state indications. During the season there were returns, first of area, then several consecutive returns of condition, then of yield per acre, and finally of production, compared with the previous year. These furnished data for three separate tests of amount of production, which were examined at the end of the season and harmonized for the final and only estimate. This was the beginning of the evolution that led to the current procedure of calculating crop production as a product of the two separate estimates of acreage and yield. During the late 1800's an increasing number of reports were received from handlers and processors of agricultural products. Their reports, which were used as supplementary indications became increasingly important, particularly as post-harvest check data on the amount of the crops.

As early as the 1880's some dealers began to interpret the reported condition of each major crop in terms of actual bushels, tons or pounds of probable yield. The desirability of having such interpretations made by the government and, therefore, available to all was recognized, and in 1912 the Crop Reporting Board began to publish forecasts of yields.
The method used originally was the so-called "par method," which assumes a proportional relationship between reported condition and final yield over the entire range of reported condition values. The inflexibility of the "par method" necessitated subjective modification of the condition index or of the pars to eliminate the disturbing effect of highly atypical years and of trends in the data. The marked superiority of the graphic regression method of translating reported condition into a forecast of yield led to the abandonment of the par method for field crops in 1930 and the adoption of the graphic regression method. However, this method did not fully explain the upward trend in yields due to the introduction of hybrid seed, improved varieties, increased use of fertilizers, mechanization and better cultural practices. Therefore, time is used as a separate variable in regression charts. The usual estimating procedure is to compute the net regression of yield on conditions taking into account time. Deviations from this line are then plotted against time. A reading of yield would be the regression value from the current condition level plus an increment for time.

The Crop Reporting Board does not forecast yield solely on the basis of reported condition. As a crop nears maturity, reporters are asked to estimate the probable average yield in their localities and the average of these crop reporters' forecasts are translated into yield forecasts by means of regression charts in which true yields are plotted against reported probable yields. For most crops, reported yields take into account weather conditions, cultural practices and other factors, consequently no adjustment for trend is necessary.

Regressions of final yield on current prospects are tools of major importance in our statistical workshop where forecasts of yield per acre are made. Current prospects which reflect the impact of weather, cultural practices and other factors to date are independent variables in forecasting equations. The impact of weather and other factors to date, as well as thereafter, is reflected in the dependent variable, final yield per acre.

It is very evident, therefore, that weather and yield forecasting are inseparably linked and that crop-weather relations are of vital concern in our work. While irrigation, mechanization and up-to-date cultural practices have given some measure of weather-proofing to crop yields, weather is still an important factor in determining yield per acre.

Since there is a logical cause and effect relationship between weather and crop yields, direct use of weather as a means of forecasting crop yields has been a challenge of long standing. Some of our earliest mathematical research in crop-weather relations consisted of simple correlation studies. In such studies, the final yield of a crop was charted against a single variable, usually monthly or total rainfall during a growing season or temperature during supposedly critical months.
It is very seldom that a single weather factor accounts for all of the variation from year to year in the yield of a crop. These studies were largely exploratory or educational and proved to be of limited use in estimating yield, except for winter wheat in the Southern and Central Plains area. In the states comprising that area, rainfall is usually light and seldom heavy enough to reduce yields. Thus, in most years a linear relationship exists, the greater the rainfall the higher the yield. Some years ago the simple rainfall-yield relations were of some use in estimating the yield per acre of wheat early in the season for that area. In recent years, however, factors other than rainfall have come into the picture and the simple realtionship is not as dependable as heretofore.

Limitations of the simple correlation studies coupled with the challenge of improving early season estimates of yield brought multiple correlation studies to the forefront. Graphic multiple correlation methods were developed showing curvilinear relations that gave the statistician an understanding of the effect of a combination of variables on yield. Regressions of final yield using various combinations of rainfall, temperature, humidity, and other indices of weather were developed for most major crops by states.

During the late 1930's detailed special crop-weather projects were carried out for cotton, corn and wheat. The projects involved special crop-weather plots at a number of experiment stations recording detailed plant and weather observations. Some exploratory work was also done at that time using complex equations. All of these studies added materially to the statistician's knowledge of crop yields in relation to weather. They showed the relative importance of weather by months, the effect of accumulated rainfall prior to the growing season and the general importance of factors other than weather.

While the correlations were significant and fairly high for some crops in certain states, the relationship when used in subsequent years would not be the same as for the years included in the study. For forecasting purposes, therefore, the previously observed relationships were misleading at times and generally much less reliable than estimates based on currently reported indices of yield per acre.

"Indirect" Weather Approach

While the so-called "direct" weather procedure in estimating crop yields per acre has not been abandoned, the emphasis has been shifted to what may be termed the "indirect" or supplemental weather approach.

In the present estimating program, considerable use is being made of multiple regressions in estimating yield with reported condition and/or yield, precipitation or indices of weather as variables.
Multiple regression equations and charts using combinations of current prospects reported by crop correspondents and precipitation as variables are being used for winter, durum, other spring wheat, corn and soybeans for some months and areas. In general, precipitation data contribute two factors to the equations: (1) accumulated precipitation for selected months before the forecast date, and (2) precipitation for the following month or combination of months. Precipitation after date has to be estimated from a knowledge of long-time trends, seasonal patterns in recent years and long-range weather forecasts. For most early season estimates, precipitation after date accounts for the major portion of the variance. The level of the indicated yield, therefore, is heavily influenced by the estimate of precipitation after the forecast date and the procedure becomes very subjective for current forecasting.

In appraising current prospects, crop reporters take into account seasonal progress, diseases, insects, quantity of fertilizer used and other cultural practices. The reported condition or yield, therefore, reflects the composite effect of weather and cultural practices to date and reporters' evaluation of such factors on final outcome. When these measures of current prospects are used as variables along with actual precipitation to date and after date, the regression coefficients measure the contribution of the components used. Any persistent tendency for farmers to underestimate or overestimate for a given pattern of rainfall, therefore, is appropriately adjusted.

In this approach we are not necessarily limited to use of actual weather data as a variable. Other factors which are, in themselves, measures of weather or effects of weather are also used. Estimating procedures for cotton and tobacco are examples of such methods.

Cotton fruits on a rather rigid time schedule in two dimensions, vertically and horizontally. For corresponding positions on the plant, it sets fruit up the stalk at about twice the outward rate along a given fruiting branch. With the fruiting rate fixed and the vegetative growth rate affected by weather and other conditions, the ratio of fruit to total vegetative growth is quite variable. Under lush growth conditions, internodes are long and the plants are large in relation to the quantity of fruit. Conversely, in periods of drought, internodes are short and the set of fruit is heavy in relation to the vegetative mass. Farmers tend to overstate prospects when plant growth is lush and understate during drought periods. It is necessary, therefore, to use an appropriate correction factor in our forecasting procedure.

The yield forecasting procedure used for burley tobacco is an interesting variation of the same general principle. To those directly involved in forecasting tobacco yields it has been apparent over the years that during the growing season procedures tend to overstate the relative yield
and condition of the crop when soil moisture is abundant and, conversely, understate its potential when drought conditions prevail. There seems to be a natural cause for this on the part of producers since the crop responds with luxuriant growth during moderately wet weather but remains nearly dormant during periods of drought. The crop has unusual ability to recover after a drought but tends to be deceptively thin and light when moisture is abundant.

To adjust for those factors we use pasture condition as one of the variables in the multiple regression equation. Pasture condition is readily available and serves as an index of soil moisture.

During the past 10 years a program involving probability area samples for use in estimating crop acreages has progressed from a limited pilot program in a few states to an operating level in 32 states and a pilot study level in 13 states for 1964. This program is intended to provide unbiased estimates of crop acreages, livestock and farm numbers and many other statistics pertaining to the farm. The probability area sample project also includes a program of objective yield studies designed to provide an unbiased indication of yield levels during the growing season and at harvest time. Objective yield studies are limited to cotton, corn, wheat and soybeans at this time, with exploratory work under way for sorghum grain. Much of the basic research work has been done through contracts with the statistical laboratories at Iowa State University and North Carolina State. Progress of the development of forecast and estimating models varies. Work is most advanced on cotton and just getting under way for soybeans. The cotton work is on an operational level in 10 states; corn is operational in 24; winter wheat operational in nine, and a pilot basis in six; spring wheat is on a pilot basis in six states. Soybean studies include surveys in 11 states, but these are still considered largely at the pilot level.

Conceptually, when a crop is mature standing in the field ready for harvest, obtaining an estimate of yield is nothing more than a sampling problem. Theory exists whereby properly designed samples of suitable size can produce sample estimates of yield with any desired precision.

**Pre-Harvest Sampling**

Techniques for estimating yields from objective counts, measurements or weights are of comparatively recent origin. Two Indian statisticians, Mahalinobis and Sukhatma, are generally credited with developing crop cutting techniques which give pre-harvest sample estimates of yield. These are based upon harvesting small sample plots of known size.
In the United States the Crop Reporting Service began experimenting with crop cutting just prior to 1940 with pre-harvest wheat surveys through the Plains States. These were discontinued after 1940 with no further work until about 10 years ago. At that time, an intensified program of objective counts was undertaken. One of the first steps taken was to approximately optimize plot sizes. Optimum sizes turned out to be rather small: two rows, 15 feet long for corn; two rows, 10 feet long for cotton; two rows, 3 feet long for soybeans; and a plot approximately 1/10 000th (0.00001th) of an acre for wheat. Experiments were conducted to find means of reducing the biases associated with these small plots. It was determined that bias could be controlled by making very precise measurements of the sample plots; by development of rules for handling border line plants, and by careful training and supervision of the samplers.

A sample design has been worked out for field and plot selection. At present, an allocation of sample fields is made to states with consideration given to the precision of both state and regional estimates. Within states a subsample is selected from the fields chosen in the spring general purpose probability sample survey. The fields in the subsample are selected with probabilities proportional to acreage, and two plots per field are located by a random process. This procedure results in a self-weighting sample of plots. Incidentally, the optimum number of plots per field appears to be something less than two, but one degree of freedom is desirable for analytical purposes, and the loss in efficiency is small.

The precision of the pre-harvest estimate of yield is of interest. A sample of 3,100 corn fields allocated to 24 North Central and Southern states gives a regional yield estimate with a standard error of about three-quarters of a bushel, and a sample of 2,150 cotton fields allocated to 10 Southern states gives yield estimates for individual states and for the region with a coefficient of variation of about 5 percent and 1 3/4 percent, respectively. The bias in the procedure for estimating corn yield has been measured by comparing sample estimates made by harvesting plots with the total production from the field; it has been found to be positive but less than 2 percent.

The timing of the objective yield surveys is geared to the forecasts and estimates published by the Statistical Reporting Service. During the growing season, forecasts of yield are made at monthly intervals beginning about two months before harvest. The surveys upon which the objective forecast of yield are based are likewise made at monthly intervals. For corn, soybeans, and cotton the first survey is made about August 1; and for winter wheat, about May 1.

At the first visit to the sample fields the plots are carefully measured off and marked so that they may be found readily. At this and
subsequent visits, the number of plants and the number of fruit by maturity classes are counted, and a sample of fruit sent in to a laboratory for weighing and determining moisture content. Then, at the last visit before harvest time, the plots are completely harvested and their yield determined. Following harvest, gleanings are collected in similar sized plots for measuring harvesting losses.

Forecasting yield is more difficult than estimating it. Direct measurements of yield can be made only when a crop is mature. When plants are immature, yield as such does not exist and hence cannot be observed directly. But, components of yield such as plant numbers, numbers of fruit, and size or weight of fruit can be counted or measured, physiological observations of plant characteristics can be made, and the components of yield projected to harvest rather well.

Plant development and fruiting tend to be orderly processes. By the time fruiting occurs, many of the factors of heredity and environment which affect the plant's capacity to produce fruit have already exerted their influence, and yield potential tends to develop unless inhibited by abnormal growing conditions. Present forecasting procedures for objective yield include no explicit environmental factors. The time lag of weather effects upon plant development is well-known and it is recognized that historical averages rarely materialize. However, the effect of weather upon the relationships underlying present procedures is not known and cannot become a part of forecasting procedures.

In order to utilize the relationships found in growth and fruiting patterns, plant maturity in terms of the point of development in the plant's life or production cycle must be known. It is desirable to infer maturity from observable plant characteristics.

When maturity is known and the relationships based upon characteristic patterns of plant and fruit development have been determined, then yield components can be projected to maturity. The relationships seem to hold rather well within varieties and geographic areas and the resulting forecasts have generally been good.

**Corn, Cotton Objective Forecasting**

As illustrations of objective forecasting procedures, let's look briefly at cotton and corn. For cotton, two different forecasting models are being used to predict the number of bolls the plant will produce. One is known as the rate of fruiting model and the other, the rate of survival. The rate of fruiting model is more complex, and because of time limitations will not be discussed here.
The rate of survival model is based upon the fact that blooms and bolls which appear on the plant during the early stages of its fruiting period have a much greater probability of surviving to produce mature cotton than those that are set after the plant is carrying a greater portion of its ultimate fruit load. The survival rates for squares, blooms and small bolls, and large bolls were determined by noting the disappearance of tagged blooms and bolls averaged over several seasons with respect to a sensitive measure of plant maturity. The present measure of maturity is the ratio of large bolls to total bolls. By means of the relationship between maturity and survival rate, the fraction of fruit on the plants that can be expected to survive and produce cotton may be predicted.

In the rate of survival model an allowance must be made for the production of bolls from plots containing no fruit at the time of the survey. A satisfactory relationship has been worked out by averaging over several seasons the number of large bolls produced with respect to the maturity ratio.

To use the probability of survival model one computes the maturity ratio, multiplies the average number of fruit observed in each category by its expected survival rate, determines the bolls expected from plots in which fruit has not yet begun to form and sums these parts to obtain the forecast of bolls at harvest.

Although average boll weight does not fluctuate greatly between years, relationships have been found which permit predicting the boll weight at harvest. As cotton begins to mature there is a relationship between the weight of the cotton from maturing bolls and the maturity ratio. This relationship is the basis for predicting average boll weight.

Although these models are based on linear approximations of historical relationships, the resulting forecasts are generally good except when upset by abnormal growing conditions. In 1963 the August 1 prediction of yield was within about 5.5 percent of that actually produced as estimated by the pre-harvest survey. The corn forecasting model is also based upon simple linear relationships which were derived from experimental observations.

At the time of the August 1 survey, the corn in some of the more northerly states has not begun to form ears. When this is the case, the number of ears to be produced is predicted by a linear regression between stalk numbers and ears produced, derived from historical data, and a historical average ear weight is also used.

When ears are present, the problem is that of predicting ear weight. Fortunately, ears attain their maximum size by the time they reach the milk stage, and equally fortunate there is a linear relationship between length of ear and weight of grain. By means of this relationship, the length of the cob measured over the husk has proven a good predictor of ear weight, provided adjustments for frost damage and early harvesting are made.
Studies have shown that dry matter is laid down in the ear until the moisture content of the grain is below 30 percent. Where early harvesting occurs, it is necessary to adjust the weight per ear for loss of dry matter as well as for moisture content.

To adjust the forecast for possible early frost, the August 1 stage of maturity is used to estimate the number of days to maturity, and by comparing this date with a historical average of first frost dates for the locality, an adjustment for the likelihood of frost damage is made.

Last season, for 11 North Central states the August 1 corn yield survey predicted averages of 58.0 ears per plot weighing .413 pounds per ear. The pre-harvest survey found 58.7 ears per plot and an average ear weight of .438 pounds. Consequently the August 1 forecast of corn yield turned out to be 4.5 percent below the pre-harvest indications.

Objective yield techniques have been developed for tree crops as well. These include oranges, lemons, peaches, pears, walnuts, filberts, and sour cherries. These techniques are based upon concepts similar to field crops. The essential differences are that the sampling unit is a tree and that the crop of fruit is set before the time of the first forecast so that it is not necessary to predict the number of fruit yet to come.

On the whole, the objective forecasting procedures in their present state of development are performing reasonably well. However, further refinements are needed in the form of more sensitive relationships that are clearly defined and which incorporate the effects of environment upon plant production.

**Work for the Future**

Work still remains to be done in the area of improvement in forecasting crop yields as well as the true yield level. There is need for more intensive studies relating crop yields to weather factors and to early season plant characteristics. Detailed phenological and environmental observations are needed; the relationship of dry matter accumulation to weather factors over the entire growth period and the use of such relationships in predicting crop yields should be explored. Then special studies need to be separated into several areas of interest: (1) phenological events such as emergence of plants, fruit emergence and fruit counts by maturity category, and (2) the mechanism of growth and development over time as related to accumulated weather factors. Any early season forecasting method would be greatly enhanced by knowledge of the weather likely to occur during the growing season within even rather large geographic areas. Through the use of new statistical techniques and modern facilities, we can predict that crop yield forecasting in the future will give greater precision and usefulness.