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CALL US the Crop Reporting Service, Crop and Livestock Estimates, Ag Estimates, or the Crop Reporting Board; and you will be correct. Although the name has changed many times, the basic service of issuing official estimates of the United States Department of Agriculture of livestock numbers, crop acreages and prospective production has continued to identify our work for over 100 years.

Forecasting production when corn is knee high, cotton just beginning to set bolls, and burley tobacco being transplanted is a vital part of our service. 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.

The fact that up until a few years ago the Weather Bureau was an agency of the Department of Agriculture was, no doubt, an expression of the close relationship between weather and agriculture. There have always been close ties between the Weather Bureau and Crop Estimates. Although the Weather Bureau is now a part of the Department of Commerce, working relations have actually been strengthened. In fact, joint weekly crop-weather reports are now issued for all States. In those reports, the weather portion is prepared by the Weather Bureau and the portion relating to crops prepared by our State Statisticians. Briefed weekly weather reports are wired to the Weather Bureau in Washington and a member of our staff prepares the National Summary on "Effects of Weather on Crops and Farm Activity" published in the Weekly Weather and Crop Bulletin issued jointly by the Weather Bureau and our Service.

These weekly crop-weather reports are making a major contribution in the area of crop-weather relations. The basic information on crop progress and farm activities is reported weekly, primarily by County Agricultural Extension Agents. The effect of weather on crops and

seasonal progress—percent planted, maturity stages, such as percent corn silked and percent harvested—as shown in these timely reports are not only of tremendous usefulness to our commodity Statisticians in providing the climate for making short-run forecasts but also to farmers and others concerned with Agriculture. Considerable effort is being directed toward standardizing these reports to make them even more useful in the future.

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. For some studies, the equation of the form,

$$Y = a + bX \tag{1}$$

and such statistical constants as the coefficient of correlation and standard error of the estimates were computed.

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 relationship 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.

This technique involved fitting an equation of the form:

$$Y = a + b_1 X_1 + b_2 X_2 + \ldots + b_n X_n \tag{2}$$

to the data. In this equation, Y represented final yield and $X_1, X_2, \ldots X_n$ represented values of the various weather factors used. Considerable time and effort were expended in calculating such equations in the late '20's and early '30's. Grinding out an equation on a hand operated calculating machine was a tremendous experience. The electrically driven calculating machine was a godsend and greatly speeded up the work

It was still a chore, however, to compute a three or four variable equation.

Fortunately, the "Bean Method" of graphic multiple correlation removed much of the drudgery from such work and weather-yield studies mushroomed. Curvilinear relations could be developed as easily as those for straight lines. Furthermore, the "Bean Method" was a logical extension of the simple correlation dot-chart procedure and gave the statistician an understanding of the effect of a combination of variables on yield that would have been difficult to get otherwise. By use of this method 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 '30'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 and 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.

The failure of the *direct* approach in the use of weather was understandable. Working with a 15-to-20-year period, several weather factors, and mostly curvilinear relationships, degrees of freedom were comparatively small. Then too, changes in varieties, drainage, conservation, fertilizer, and other cultural practices and combinations of weather not adequately reflected in the regression period would come into the picture.

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.

The general equation for wheat would be of the following order:

$$Y_c = a + b_1 X_1 + b_2 X_2 + b_3 X_3 + b_4 X_4 + b_5 X_5. \quad (3)$$

Y = final yield per acre

X_1 = condition
X_2 = reported yield
X_3 = precipitation prior to estimating date
X_4 = precipitation after estimating date
X_5 = time (trend)

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. Long-time averages are not used except as a last resort. For most early season estimates, precipitation after date (X_4) accounts for the major portion of the variance. The level of the indicated yield, therefore, is heavily influenced by the estimate of precipitation after date and the procedure becomes very subjective for current forecasting. To avoid some of this difficulty corresponding equations omitting precipitation after date are being developed for supplementary use.

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 under or over-estimate 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. Con-

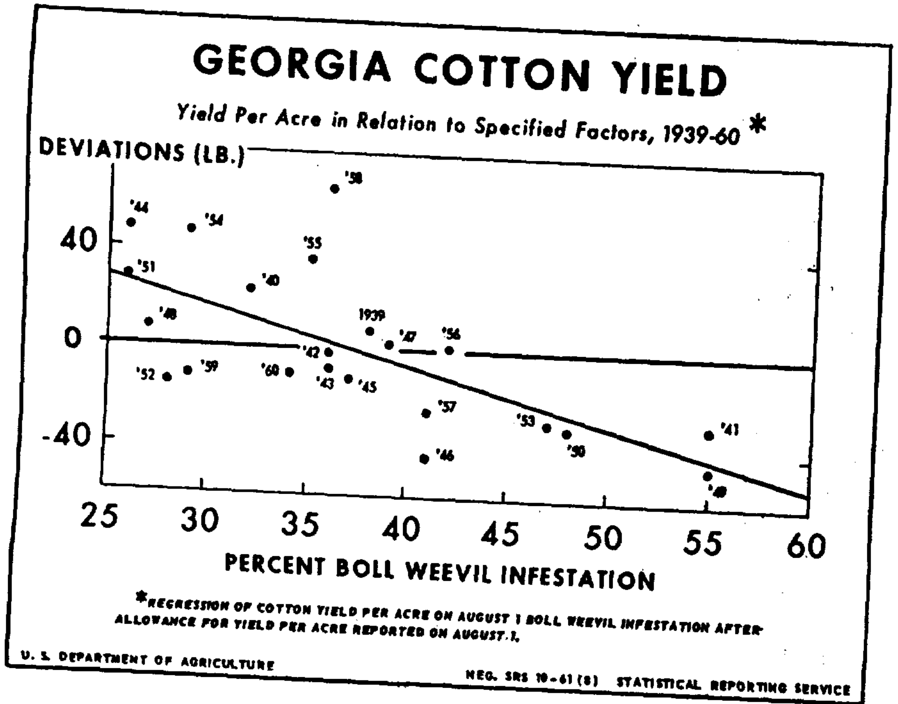

CHART 1

versely, 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.

While the adjustment is needed primarily for weather conditions, the correction factor actually used is boll weevil infestation. Weather and weevil infestation are inversely correlated and the single correction factor makes simultaneous adjustments for both weevils and weather. High temperature and drought tend to control weevils and limit plant growth. Under those conditions adjustments are positive; that is, yields turn out better than expected currently. On the other hand, cool, wet weather promotes weevil infestation and excessive plant growth and regression adjustments are negative. (Chart 1)

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 producers 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 remain 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. As was the case with cotton, persistent tendencies for specific patterns of weather are adjusted. (Chart 2)

During the past 5 years a pilot operating program involving probability area samples for use in estimating crop acreages has been under test in several States. For wheat, corn, and cotton, the project also included making specific counts and measurements on plants in sample areas of fields around the first of the month during the growing and pre-harvest seasons for use in estimating yield per acre. The sample areas were harvested, and weights and moisture content determined.

The project was stepped up to the operating level in 10 southern and

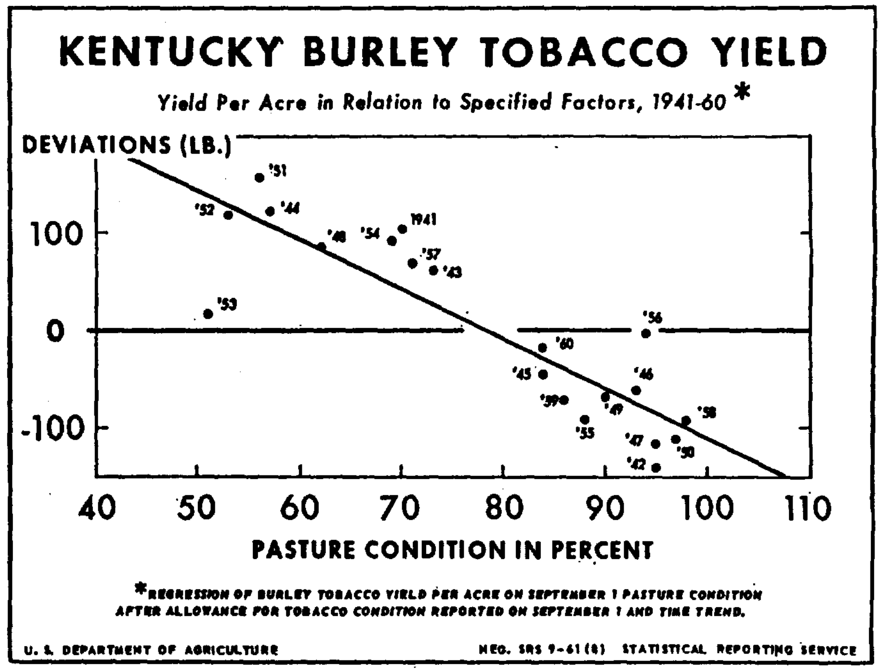

CHART 2

5 Corn Belt States in 1961. Long range plans call for additional States to be brought into the program as funds become available.

These objective counts and observations add new facets to estimating yield per acre. They also reflect the impact of weather and cultural practices to date and may be of help in bringing to light additional information on crop-weather relationships.

For many crops, the initial forecast for the season is made while plants are still in the vegetation stage. Under those conditions, unusual weather can cause considerable change before harvest. For such crops, reliable long-range weather forecasts would be a major break-through in improving estimates, but these seem doubtful in the near future.

There is some question as to whether use of weather data just prior to, or at time of harvest would result in more reliable estimates of yield per acre. At that time, the correlation of yields per acre as reported by crop reporters and actual yields is very high. Long range weather forecasts, crop-weather relations, and objective crop observation, however, hold considerable promise for improving early season yield estimates, especially when viewed in the light of electronic data processing.

At present, there is great need for special studies, similar to but more extensive than those conducted in the late '30's, relating major crop yields and weather factors. Detailed phenological and environmental observations are needed. In addition, 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. These special studies need to be broken into several areas of interest: (1) phenological events such as planting, emergence of plants, fruit emergence, and fruit counts by maturity categories, and (2) the mechanism of growth and development over time as related to accumulated weather factors.

The weather observations should be made within the experimental fields or plots and should include air and soil temperatures, maximum and minimum temperatures, net radiation, evapotranspiration, soil moisture, frost formation, rainfall, and dewpoint. Most of these studies should be conducted at Experiment Stations as was done in the '30's. In some cases good use could probably be made of controlled environments to accumulate many different weather conditions within a relatively few years. This type of detailed information is vitally needed in conjunction with objective yield observations and is also of considerable importance in crop breeding. In addition, such studies would be valuable information on the development and quality of the crop.