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A Centenary Profile of Methods for Agricultural Surveys

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The Early Years

One hundred years ago crop reporting was officially established in the U. S. Department of Agriculture by a $20,000 item in the Appropriation Act. The Department was then only four years old. Long before that time the need for statistical information was realized and limited efforts to supply it had been made, but it was not until 1866 that USDA began issuing nationwide crop reports on a continuous basis.

Data from the decennial censuses of agriculture, first taken in 1840, were basic to the calculation of estimates. Intercensal published reports were based upon inquiries sent to farmers, who were requested to answer for the localities with which they were familiar rather than their farms, on the assumption that the wider coverage would provide more accurate results. The most important factors involved in selecting correspondents were evidently good geographic representation and intelligent, literate farmers with ability to judge crop prospects and year-to-year changes. The inquiries requested information on acreage harvested and numbers of livestock as a "percentage of last year." Farmer reporters also were asked annually to give information on prices received for agricultural products and wages paid to farm laborers.

Condition and yield per acre of crops were generally published as State and national averages of reporters' returns, as were prices and wage rates. Percentage changes in acreages of crops harvested and in numbers of livestock were published as reported or as adjusted together with the calculated estimates of State and national totals.

Very early in the history of crop and livestock reporting, the statisticians recognized response error as a major source of error in some instances. A good example was cash crop bias resulting from the tendency of the crop reporters to be over-conservative in reporting condition and yield per acre of crops grown for sale, especially before much of the crop was sold. Parenthetically, it should be noted that census returns suffered from this same cash-crop bias, though to a lesser extent because censuses were ordinarily taken at post-harvest and often post-sale dates. There was also an apparent failure of the year-to-year changes indicated by farmers' reports to reflect the rapid changes in crop acreages and livestock numbers that were taking place in the expanding agriculture of the period. The art of statistics was still in its infancy, as evidenced by statements issued with some early reports on such elemental matters as the definition of a weighted average as distinguished from a simple straight average. However, the urge toward experimentation and improvement appears to have kept pace with that in other fields of inquiry.

In general, the estimates continued through the nineteenth century to be "tied" to the decennial censuses, with estimates for the intercensal years based upon reports from farmers indicating percent change from the preceding year. In light of present day knowledge, the collected data were obviously subject to various biases of judgment and sampling. The returns could not be taken at face value and the estimation process was crude and subjective.

Surprisingly, in view of the very limited funds available for the work, those in charge continued to issue statistics for an increasing number of States and an increasing number of crops. They displayed considerable ingenuity in filling gaps in series by republishing information gathered and put out by commercial establishments. Thus, wholesale prices of the principal crops at the principal city wholesale markets were issued from the market quotations beginning in 1866. Wholesale prices for livestock and livestock products were begun in 1894.

First Quarter of the Twentieth Century

By 1900 the statistical program was becoming much better organized and effective in meeting the needs. The following observations made in 1904 by Mr. John Hyde, Chief of the Division, may be pertinent for all time: "Criticism is not lacking. On the contrary, it is one of the curious features of this work that the more closely reports represent the actual facts and the wider the appreciation of their accuracy the more subject they become to criticism. This is undoubtedly due to the fact that as their general accuracy is more and more widely recognized they necessarily exercise a greater influence upon the markets, thus inevitably favoring or antagonizing, as the case may be, some of those who are engaged in the game of speculation in agricultural products. This immediately attracts the adverse comments of the losers. This result is unavoidable, and is apparently the inevitable penalty the Department must pay for issuing reports so reliable and so generally appreciated as to have instant effect on the markets. Were the reverse true, and were these reports regarded as unreliable, they would not influence prices, and criticisms would be reduced to a minimum."

The first two decades of the twentieth century were notable for the inauguration of monthly reports of prices received by farmers and of prices paid by farmers for production goods and household maintenance supplies. This important change was first made for crops and livestock commodities in 1908, and for purchased farm supplies in 1910. At the same time, names of local dealers were incorporated into the lists of respondents, who were an important new and better source of information. The new series of prices proved to be invaluable data for setting up "pre-war" prices and indexes, 1910-14, which much later played such an important role in administering the Agricultural Adjustment Program.

Because of the importance of publishing reliable reports, agricultural statisticians spent much effort without the aid of sampling theory, on the development of means for appraising the accuracy of estimates and forecasts. The primary basis for this was after-the-fact comparisons with data from various sources commonly referred to as check data. Because of the nature of some sources of error as well as the 10-year lapse between censuses, efforts were made to develop and use data from independent sources—for example, carlot shipments of fruits and vegetables, ginning reports to the Bureau of the Census on bales of cotton ginned, receipts at mills and elevators, and receipts of livestock at stockyards and packing plants, tax records, etc. Data from such sources, in addition to census data, were used as information for revising estimates. Thus, past comparisons between data reported by farmers and the final revised estimates became an increasingly important basis for interpreting and converting current reports from farmers into estimates.

Except for data on crop condition for use in preparing production forecasts, a general shift from the use of "locality" as a reporting unit to the individual farm took place during the second decade of the 20th century. For example, in June, when surveys of planted acreages were made, the questionnaires were designed so a farmer gave for his own farm the acres for harvest in the current year and acres harvested in the preceding year. While the returns had biases due to selectivity of reporters, memory biases as to the actual acreages in the preceding year, and in some cases deliberate under or overstatements, they were distinctly superior to the judgments of change in localities. They more accurately reflected large changes from one year to the next, were better indications of relative areas of each crop, and statistically were more sound. Incidentally, some degree of bias could be determined by matching returns for two successive years. It was not until the 1920's when the "farm" generally replaced the "locality" as a reporting unit.

Cooperation with the Post Office Department, beginning in 1922 for livestock and in 1924 for crops, provided an additional source of information. By agreement between the Postmaster General and the Secretary of Agriculture, the rural mail carriers were instructed to distribute questionnaires (cards) to mail boxes. This was not preselected sampling. Instructions have varied but in general each mail carrier was asked to leave cards in consecutive boxes along a portion of the route which he felt would be fairly representative of the entire route taking into consideration all kinds of farms. This provided a much larger sample than previous methods and the returns were considered to be less selective. Current and preceding year information was requested at first, but eventually the preceding year was dropped from the questionnaires and for purposes of estimation principal reliance placed upon a weighted ratio of each crop acreage to farm land. However, year-to-year changes indicated from matched farms were also used as information in the preparation of estimates. Crop reports and livestock reports, although differing with respect to timing and frequency, have in general been based on similar methodology since about 1920.

In 1911, the Department of Agriculture ventured to translate farmer reports on crop condition into yield per acre by a procedure known as the par method. Condition figures, which were farmers' appraisals of a crop expressed as a percent of normal, had been collected for many years and reports on condition had been issued, but not in terms of forecasts of yield per acre. The par method converted condition reports into yield per acre by simply multiplying the current average condition by "par". A separate par was established for each State, crop, and month. It was the ratio of the preceding 10-year average yield, $\bar{y}$, to the 10-year average reported condition, $\bar{c}$. Thus, the forecasting model was simply a line determined by the two points (o, o) and $(\bar{c}, \bar{y})$. However, subjective modification of the pars was regarded as necessary to eliminate the disturbing effects of atypical years and of trends in the data. This method was abandoned in the 1920's in favor of more advanced regression techniques.

Introduction of Regression Techniques

Following World War I, innovations in methodology accelerated. There was a shift toward more dependence on proficiency in statistical technique without deemphasizing knowledge of agriculture and ability to appraise crop prospects. By 1925, the application of regression techniques was being explored. Data for a sufficient number of years had been accumulated so final revised estimates could be plotted against averages of reports from farmers. Thus, regression techniques provided a means of translating survey data into estimates and of adjusting for persistent bias in the data. This approach was a major advance in methodology which replaced the par method for yield forecasts and was then adopted quite rapidly for all crop and livestock surveys because voluntary responses to mailed questionnaires constituted a selective sample and estimating techniques that would remove as much bias as possible were very important. In general, mathematical methods were not used to fit regression lines. Instead, graphical methods were used primarily because of the lesser amount of time and effort involved and to allow flexibility in the application for special circumstances.

With continued improvement, this relatively low cost methodology [1] involving mail surveys and regression techniques has been a mainstay for many years and is still used except for surveys based upon probability sampling. It has been most reliable during periods when the structure of agriculture was not undergoing sharp or cumulative changes, when surveys are made regularly, and when the data used to make a current estimate are subject to the same kind and degree of selectivity that existed in previous survey data on which the regression was based. Important changes in relationships have occurred owing, for example, to changing concepts of the sizes of fields resulting from agricultural adjustment programs, the shifting of whole farms into soil bank categories, and the consolidation of farm holdings.

New methods of sampling for crop acreages and yields were also a subject of much interest during the 1920's, though limitation of funds did not permit widespread investigation. Beginning in 1916, the agricultural statistician for South Carolina counted the number of fields in cotton, corn, and other important crops in his State from train windows. In 1921, when a program to reduce cotton acreage by one-third was advocated in the press and at farmer gatherings, the subjective inquiries indicated a considerable reduction. The statistician's field counts showed only half as much reduction and the final acreage estimates sustained his counts. This episode encouraged other field men to make counts of fields and counts of telephone poles opposite crops as a rough indication of acreages. In 1923, the agricultural statistician for Mississippi made the first crop meter, an instrument attached to the speedometer cable of an automobile for measuring frontage of various crops along the highway [2]. In 1925, a statistician in North Carolina submitted a plan for counting numbers of cotton plants, bolls, etc., in field plots consisting of 15 feet of a row of cotton. Such counts were made in increasing numbers in the succeeding years by the staffs of the central and field offices. Arrangements on an experimental basis were made to have farmer crop reporters make counts and measurements in plots chosen at random and to report at monthly intervals during the growing season. While the results of these experiments were not sufficiently extensive for general use, they demonstrated the desirability of further development.

The Drive for Improved Methods

Throughout the Century there was a persistent, strong demand for additional and more accurate information. However, during the thirties such demands were unusually keen because of the depression, the impact of the "Dust Bowl," the development of agricultural adjustment programs, and the acceleration of new farming practices. Thus, the pressures for finding new approaches to survey sampling and estimation were mounting. Reliable methods that were not dependent upon historical relationships as bases for estimation were especially needed when new statistical series were introduced and for "single-time" surveys.

In the thirties, the Department of Agriculture intensified its effort to develop improved methodology. The need for reliable statistics on production in administering the programs under the Agricultural Adjustment Act of 1933 led to the allotment of funds for special inquiries on yield. The most significant of these were the 1939 and 1940 preharvest wheat surveys in which wheat fields along specified routes were selected by means of the crop meter. From Texas to North Dakota, samples of grain from the selected fields were obtained for yield and quality determinations [3].

The Bankhead Jones Act, 1935, provided for an expansion of research on basic problems confronting agriculture. In 1938, an allotment from these funds was obtained to implement a cooperative research program, with the Statistical Laboratory at Iowa State University, for the purpose of developing appropriate theory and techniques of sampling and estimation. A similar cooperative research program was inaugurated in 1940 with the University of North Carolina at Raleigh. Also, in 1938, a large project [4] was started in New York, under the Work Projects Administration, for experimenting with various sampling and estimation procedures including area sampling based on aerial maps provided by the Agricultural Adjustment Administration.

There were two major phases of the research program, one dealing with methods of forecasting and estimating crop yields and the other with sampling methods for farm surveys generally. With respect to crop forecasting, many investigations were conducted relating data on crop yields to weather data or to plant counts and measurements taken during the growing season. Several exploratory preharvest surveys (crop cutting) were also conducted using a sample of fields and a subsample of about two small plots within each. These preharvest trial surveys involving objective means of estimating crop yields and quality were very encouraging. On the other hand, results of the studies of methods for forecasting were not so promising. The forecasting problem was obviously more involved and of a longer term nature because of the need for several years' data to develop and test models.

The research work on crop forecasting was discontinued during World War II. When resumed after the war, effort was focused primarily on the development of models based upon plant measurements during the growing season. It had become increasingly clear that the relationship between weather and yield was extremely complex. Moreover, any weather-yield model would always be out of date to some degree because of changing farm practices and the introduction of new varieties. Presumably the plant itself reflects a composite effect of its environment. Hence, there was a feeling that measures of plant growth or development provided better prospects for success than measures of things affecting the plant. Also, the problem of keeping the model current, because of changing farm practices, seemed less formidable.

Experience indicated that correlations between plant observations on a given date and yield were generally inadequate, apparently because of variation from year to year in the stage of plant growth. Thus, attention was turned to the development of models incorporating measures, at time of observation, of the stage of plant growth which could replace calendar date as a time reference. Incidentally, such models have an operating advantage owing to a lesser need for tight control on the timing of field work. This change in approach proved to be a very important one as much progress was made during the fifties on the development of reliable models for forecasting yields of several crops. In fact, these developments have culminated in an operating program for cotton, wheat, corn, soybeans, and several tree crops. The work on forecasting crop yields will not be discussed further as it has been summarized in a recent paper by Houseman and Huddleston [5].

Let us return to the other major part of the research program that was started in the late thirties. Considerable thought was being given to the possibility of a large annual sample survey because of the need for better data and of the cost of an annual census of agriculture. Hence, although the interest in developing improved sampling methods was general, there was a central question. If an annual sample survey of agriculture were to be taken, how should the sample be designed? At this time stratified random sampling was rapidly gaining favor over purposive sampling. Also, as a complete current list of farms did not exist, the stage was ready for the development of probability area sampling. There had been some earlier exploration of the possibilities of area sampling, notably the consideration of townships as sampling units, but there were two area sample surveys in Iowa, 1938 and 1939, that are of historical significance [6]. These surveys provided much data for study of components of sampling error, methods of stratification, methods of estimation, size of sampling unit, cost components, and optimum design.

The development of area sampling in agriculture escalated to the preparation of an area sampling frame for all counties and the selection of an area sample, approximately five percent, which was known as the Master Sample of Agriculture [7]. This was a cooperative project involving Iowa State University, the Statistical Reporting Service, and the Bureau of the Census. The term "Master Sample" was coined in anticipation of its being subsampled for many surveys involving a wide variety of purposes. It was used in conjunction with the 1945 Census of Agriculture to collect supplemental information, but its expected role as a large sample that could be subsampled for many purposes never materialized. Although it was subsampled many times, the area frame itself turned out to be of greater importance for sampling purposes. As soon as the means for area sampling became available, it was generally used for "single-time" surveys except for the infrequent cases where a suitable list frame existed. A number of attempts were made in the 1940's and early 50's to establish some recurring surveys based on probability area sampling but resources were inadequate to sustain such efforts.

Competition for the Statistical Dollar

Accuracy, timeliness, and content have been generally recognized as three important attributes of statistics that should be continuously under appraisal and endeavor for improvement. But, these three factors compete for the resources used to produce statistics and, unfortunately, the support for them has been unbalanced. For example, there has frequently been strong support for funds for additional data in sharp contrast to lack of support for funds for research and program modifications needed to improve accuracy or even maintain reasonable levels of accuracy. This omission can be grievous when increasing complexity and rapid changes in the structure of the statistical population are taking place, as in Agriculture. Over a long period of years changes in statistical technique that can be implemented without additional resources for that purpose may be seriously inadequate. Because of the strong demands for statistical data, improvement in accuracy is virtually impossible to attain at the expense of reduction in content or frequency of reports or from savings that might accrue to relaxation of timing requirements.

In 1951, the forecasts of cotton production varied from final estimates by an unusual amount. This attracted the attention of Congress and the public to shortcomings in methods of making agricultural estimates and among other things led to an appropriation for methods research and development. Prior to this time, no funds for research on methods had been included in the regular appropriation for statistics, so the research effort had been inadequate. In 1954, the research and development program was expanded. On a small scale, farm surveys designed to test and develop techniques and to provide data for variance analyses regarding sample design and methods of estimation were conducted. Also, to further explore and develop methods for forecasting crop yields, plant measurements were taken more extensively, than heretofore, in sample plots in sample fields.

Long Range Plan for Improvement

In 1957, a four-part plan for the improvement of agricultural statistics was presented to Congress. As a means of meeting the mounting demands for greater detail and accuracy, highest emphasis and priority was given to part one of the plan, namely, the establishment of improved facilities that would enhance accuracy, provide a more technically sound statistical foundation for present and additional statistics, and a more flexible system for keeping pace with the rapidly changing structure of agriculture. Part two of the plan pertained to the strengthening of price statistics. The objective of part three was reduction in lapse of time between data collection and release of reports and more frequent reports during critical periods. Part four considered the needs for additional data and services. From here on our discussion will be limited to activity under part one, which is now nearing completion.

Followed by a period of pilot operations for perfecting techniques, the first major increment of funds for implementation of part one of the long-range program was appropriated beginning with fiscal year 1961. The plan for implementation provided for introducing the program for a group of States at a time, first on a pilot basis to gain experience and then on a full operational basis. The major part of this program consists of two surveys each year based on probability area sampling. The first, occurring near the first of June, is primarily a crop survey of acreages planted whereas the second is mostly a livestock survey taken near the first of December. For the program of crop yield forecasting from plant measurements, referred to earlier, subsamples of fields identified in the June survey are selected with probabilities proportional to size for observation during the growing season. However, attention from hereon is focused on the June and December surveys and some of the techniques pertaining to them. Any reader who is interested in a full description of the scope and methods involved in the agricultural statistics program of the Statistical Reporting Service is referred to a publication issued in 1964 [8].

Some Operating Problems

Although much experience with area sampling had been accumulated since about 1940, there were a number of operating problems that needed further investigation before launching a large-scale survey operation. The field operation of identifying sampling units (area segments) is complex. Supplying aerial photographs on which segment boundaries have been delineated eliminates most of the ambiguity about location of boundaries. The real difficulty is ambiguity in the identification of farms and in associating farms with segments. Area sampling, with farms as reporting units, involves establishment of a farm headquarters (unique identification point) for each farm. The criterion for deciding whether a farm is in the sample is whether its headquarters are within the boundaries of a sample segment. New and better operating techniques were sought as the results of the field work must conform quite rigorously with the concepts involved, or much of the advantage of probability sampling is lost.

When the research program was expanded in 1954, it was decided that the "closed segment" concept should be tried. The idea of the closed segment is to account in a rigorous manner for all of the land, livestock, etc., within the boundaries of the segment at the time of the interview regardless of what farm, or part of a farm, may be involved. Thus, the basic unit for enumeration becomes a "tract" which is a farm or part of a farm within a sample segment. For the kind of data where this concept is applicable there are two important advantages. One is a substantial reduction in sampling error, particularly for crops, because of less variation in size of segment, especially when the method of estimation is direct expansion by the reciprocals of the probabilities of selection. Secondly, for some items the nonsampling errors are less. An obvious disadvantage is that some objectives can be served only when farms are the reporting units.

The idea of defining a sampling unit as consisting of all farms entirely or partly within the boundaries of a segment was considered and tried. For those farms not entirely within a sampling unit, varying probability of selection is introduced and this must be taken into account in the estimation procedure. This way of defining a sampling unit eliminates ambiguity associated with identification of farm headquarters, but the efficiency is low in terms of sampling variance per dollar. At present the closed segment is being used for some sections of the questionnaire; the open segment, in terms of farms with headquarters within the sample segments, is being used for other sections.

Design of the National Area Sample

Sample design was another matter that received much attention. In terms of sampling error per dollar, research indicated that a single stage sampling plan should be used and that it was feasible to reduce the size of sampling unit by one-half. That is, one-half the size of the sampling units established several years earlier when the area sampling frame for the so-called master sample of agriculture was prepared. The sampling units currently being used average less than two farms. The research results showed that reducing the size of segments by one-half would increase sampling variance by only 20 percent. Hence, a 50 percent reduction in segment size could be offset by a 20 percent increase in number of segments. For the same precision, this enabled a reduction of about 25 percent in the cost of enumeration and cut the number of interviews by approximately 40 percent.

In June 1967, the area sample will be on a fully operational basis for the first time in all of the 48 conterminous States. It will consist of about 17,000 segments. Approximately 30,000 farm operators, less than one percent of the national total, reside in these segments but parts or all of nearly 70,000 farms are involved under the closed segment concept. The sample was designed as a general purpose sample. Its allocation to States was based on the diversity and importance of the agriculture within States and the dual objective of State and national estimates. Except as noted below, within each State the sample was allocated to Crop Reporting Districts (which are generally related to type of farming) in an optimum manner on the basis of variance and cost analyses that were obtained when the State was operating on a pilot basis. Simple geographic stratification is used within Crop Reporting Districts.

For the December survey, which is primarily a livestock survey, a subsample of about one-fifth of the tracts enumerated in June is selected. Tracts classified as non-agricultural are subsampled at a very low rate, as agricultural but non-livestock at an intermediate rate, and as livestock at a heavy rate. This subsample of the June area sample is supplemented with a sample of nearly 4,000 farms selected from a list of about 12,000 operators of large livestock farms. The present situation regarding supplementation of area sampling with list sampling is quite fluid for reasons indicated later.

The area sampling frame being used is the one completed in 1944 for the master sample of agriculture except for new frames constructed for western and northeastern States. Huddleston [9] has described them in detail. In addition to the advantage of having better cartographic material, improvement accrued to the delineation of broad land use strata related to intensity and kind of farming as major strata for optimum allocation of the sample in lieu of Crop Reporting Districts. The new frames provided reduction in sampling variance ranging from 10 to 25 percent depending upon the item.

Field Work and Data Processing

In the field operations much emphasis is placed on quality with economy. A small headquarters staff designs the survey forms, prepares fully illustrated instruction manuals, and conducts intensive training for professional State supervisors who are responsible for the selection, training, and supervision of part-time interviewers. In addition to formal training including field practice, interviewers receive instruction manuals and on-the-job supervision during the survey work. Many self-checking features are built into the survey questionnaires. Aerial photographs are used for positive identification of sample segments and as a means for accounting for all land area. By planimeter, the land area of each segment is determined and used as a check by comparison with the sum of reported acreages in individual fields or tracts. Also, a small portion of each interviewer's assignment is checked by re-interview by supervisory personnel.

Elaborate computer programs have been used for processing the data. These programs provide for five different estimators including direct expansion, two ratio estimates, difference estimates, and censored estimates. The latter reduce variance attributable to extreme values. In addition to the five estimators and sampling standard errors for each, the program provides for the computation of 5 to 7 components of variance depending on the sample design.

A Few Comments on the Immediate Outlook

As the establishment of the June and December surveys on a national basis nears completion, increased attention is being given to adjustments in the total statistics program in order to accomplish as fully as possible the original mission of part one of the long-range program for improving agricultural statistics. This entails the relationship in terms of sampling frames, design, and estimation between the June and December probability area sample surveys and other surveys conducted during the year, generally by mail, on a wide variety of items. Many of these other surveys are of a special purpose character, requiring samples designed for specific commodities. The general-purpose design of the area samples for the June and December surveys will probably be retained for many years even though the marked trends toward specialization in agriculture continue. However, the trend toward large, specialized farming operations calls for much greater emphasis on the development of special sampling frames and possibly the use of multiple frame sampling.

Multiple frame sampling poses difficult operating problems related to the identification of farms but such problems are common, to some degree, to all methods of sampling. However, good list frames properly constructed, even though incomplete, have much potential for improved sampling. With suitable list frames, the area sample for the June and December surveys would probably be reduced and supplemented to a greater extent with samples drawn from the lists. The list frames could also provide an improved basis for sampling for the many surveys conducted by mail during the year. A common set of sampling frames for all agricultural surveys has potential for providing links between the mail surveys and the June and December interview surveys that would improve the mail surveys. In recent years multiple frame sampling involving list and area frames has been used on several occasions and alternative concepts or procedures have been subjected to field testing. Although it is anticipated that multiple frame sampling will receive much attention during the next few years, its practical applicability is far from established.

At times it has been difficult to keep part one of the long-range program for the improvement of agricultural statistics pointed toward its original purpose, because of strong demands for additional data in various commodity areas. A wider appreciation is needed of the simple fact that investments must be made in "plant" improvement, in this case the basis for agricultural statistics, if there is to be a good solidly based response to the changing statistical needs in our modern society.

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