CRC Handbook of Agricultural Productivity

Volume I
Plant Productivity

Miloslav Rechcigl, Jr., Editor

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PREFACE
CRC SERIES IN NUTRITION AND FOOD

Nutrition means different things to different people, and no other field of endeavor crosses the boundaries of so many different disciplines and abounds with such diverse dimensions. The growth of the field of nutrition, particularly in the last 2 decades, has been phenomenal, the nutritional data being scattered literally in thousands and thousands of not always accessible periodicals and monographs, many of which, furthermore, are not normally identified with nutrition.

To remedy this situation, we have undertaken an ambitious and monumental task of assembling in one publication all the critical data relevant in the field of nutrition.

The *CRC Series in Nutrition and Food* is intended to serve as a ready reference source of current information on experimental and applied human, animal, microbial, and plant nutrition presented in concise tabular, graphical, or narrative form and indexed for ease of use. It is hoped that this projected open-ended multivolume compendium will become for the nutritionist what the *CRC Handbook of Chemistry and Physics* has become for the chemist and physicist.

Apart from supplying specific data, the comprehensive, interdisciplinary, and comparative nature of the *CRC Series in Nutrition and Food* will provide the user with an easy overview of the state of the art, pinpointing the gaps in nutritional knowledge and providing a basis for further research. In addition, the series will enable the researcher to analyze the data in various living systems for commonality or basic differences. On the other hand, an applied scientist or technician will be afforded the opportunity of evaluating a given problem and its solutions from the broadest possible point of view, including the aspects of agronomy, crop science, animal husbandry, aquaculture and fisheries, veterinary medicine, clinical medicine, pathology, parasitology, toxicology, pharmacology, therapeutics, dietetics, food science and technology, physiology, zoology, botany, biochemistry, developmental and cell biology, microbiology, sanitation, pest control, economics, marketing, sociology, anthropology, natural resources, ecology, environmental science, population, law politics, nutritional and food methodology, and others.

To make more facile use of the series, the publication has been organized into separate handbooks of one or more volumes each. In this manner the particular sections of the series can be continuously updated by publishing additional volumes of new data as they become available.

The Editor wishes to thank the numerous contributors many of whom have undertaken their assignment in pioneering spirit, and the Advisory Board members for their continuous counsel and cooperation. Last but not least, he wishes to express his sincere appreciation to the members of the CRC editorial and production staffs, particularly President Bernard J. Starkoff, Earl Starkoff, Sandy Pearlman, Pamela Woodcock, Lisa Levine Eggenberger, John Hunter, and Amy G. Skallerup for their encouragement and support.

We invite comments and criticism regarding format and selection of subject matter, as well as specific suggestions for new data which might be included in subsequent editions. We should also appreciate it if the readers would bring to the attention of the Editor any errors or omissions that might appear in the publication.

Miloslav Rechcigl, Jr.
Editor-in-Chief

PREFACE

HANDBOOK OF AGRICULTURAL PRODUCTIVITY

The greatest challenge of our time is to produce sufficient food to keep pace with the rapidly growing population. In the opinion of experts, during the next 25 years there will be a need for as much food as was produced in the entire history of mankind to date. Of the various measures available, improvement in agricultural productivity is judged as the ultimate means of augmenting food production and supplies.

In this Handbook, an international team of experts consider the most important factors affecting production of both crops and livestock. This Handbook is intended as a scientific guide to practitioners and students, as well as to researchers, who should find here stimulating ideas for further exploration.

THE EDITOR

Miloslav Rechcigl, Jr. is a Nutrition Advisor and Chief of Research and Methodology Division in the Agency for International Development.

He has a B.S. in Biochemistry (1954), a Master of Nutritional Science degree (1955), and a Ph.D. in nutrition, biochemistry, and physiology (1958), all from Cornell University. He was formerly a Research Biochemist in the National Cancer Institute, National Institutes of Health and subsequently served as Special Assistant for Nutrition and Health in the Health Services and Mental Health Administration, U.S. Department of Health, Education and Welfare.

Dr. Rechcigl is a member of some 30 scientific and professional societies, including being a Fellow of the American Association for the Advancement of Science, Fellow of the Washington Academy of Sciences, Fellow of the American Institute of Chemists, and Fellow of the International College of Applied Nutrition. He holds membership in the Cosmos Club, the Honorary Society of Phi Kappa Pi, and the Society of Sigma Xi, and is recipient of numerous honors, including an honorary membership certificate from the International Social Science Honor Society Delta Tau Kappa. In 1969, he was a delegate to the White House Conference on Food, Nutrition, and Health and in 1975 a delegate to the ARPAC Conference on Research to Meet U.S. and World Food Needs. He served as President of the District of Columbia Institute of Chemists and Councillor of the American Institute of Chemists, and currently is a delegate to the Washington Academy of Sciences and a member of the Program Committee of the American Institute of Nutrition.

His bibliography extends over 100 publications including contributions to books, articles in periodicals, and monographs in the fields of nutrition, biochemistry, physiology, pathology, enzymology, molecular biology, agriculture, and international development. Most recently he authored and edited *Nutrition and the World Food Problem* (S. Karger, Basel, 1979), *World Food Problem: a Selective Bibliography of Reviews* (CRC Press, 1975), and *Man, Food and Nutrition: Strategies and Technological Measures for Alleviating the World Food Problem* (CRC Press, 1973) following his earlier pioneering treatise on *Enzyme Synthesis and Degradation in Mammalian Systems* (S. Karger, Basel, 1971), and that on *Microbodies and Related Particles, Morphology, Biochemistry and Physiology* (Academic Press, New York, 1969). Dr. Rechcigl also has initiated a new series on *Comparative Animal Nutrition* and was Associated Editor of *Nutrition Reports International*.

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Physical Environment

CLIMATIC VARIABILITY AND PLANT PRODUCTIVITY

James D. McQuigg

SYNOPSIS

There are two basic approaches to modeling the impact of meteorological variability on crop yields. The physiological approach is an attempt to describe the detailed impact of meteorological variability on biological/physical processes that occur within a typical plant or a plant canopy. The statistical approach is an attempt to use a sample of yield data from an area (an experimental plot, a crop district, state, province, etc.) and a sample of weather data from the same area to produce estimates of coefficients in the model by some sort of regression technique.

THE PHYSIOLOGICAL APPROACH

Another name for this approach is "causal." Ideally, a model of this type should be based on detailed knowledge of the biological/physical processes which take place (hour-by-hour, or day-by-day) within the plant and within the immediate atmospheric/soil environment of the plant. This knowledge, expressed in quantitative form, is the model. Such a model is very useful for a variety of purposes, serving as a scientific tool for

1. Studying the impact of climate change
2. Deliberate genetic "engineering" leading to better adaptation of a crop to a given range of climatic conditions
3. Estimating crop yields
4. Estimating the phenological progress of a crop, given knowledge of weather conditions

While it is surely true that investigators in a number of disciplines have developed an impressive body of detailed, quantified knowledge of the many complex processes that occur within plants and within the immediate environment of plants, a model based directly and only on such biological/physical knowledge does not exist.

Many of the models of this type that have appeared in the literature are consistent with one or more causal mechanisms within the crop and within the immediate environment of the crop, but coefficients in the models are often the result of regression/correlation analysis of sample greenhouse or experimental plot observations.

The reader not already familiar with the physiological approach is referred to the papers by Haun,[3] Runge,[4] and DeWit et al.[2] The major advantage of this approach is that it is based on knowledge of causal relationships. The major disadvantages of this approach are that the knowledge of causal relationships between weather events and biological/physical processes within the plant or the plant canopy is incomplete, and detailed measurements needed to estimate the coefficients in a physiological model are limited to comparatively small sample plots and short sample periods. The problem of extending the results of physiological modeling for specific locations to aggregated estimates of crop progress, or of final yield over commercially important large regions, has not been completely solved.

THE STATISTICAL APPROACH

Another name for this approach is "correlative." In this case, the investigator usually has access to a series of yield estimates from an area (which may be as small as a research plot or as large as a whole country) and a sample of weather data from the same area. Using some sort of regression technique applied to the yield and weather data, coefficients in the model are estimated.

At its worst, the regression work proceeds as a "cut and try" effort to look at almost all possible specifications of the weather variables that could be included in the model. At its best, the specification of the form of the model is made in a manner that is consistent with the most complete knowledge of biological and physical processes.

The chief advantage of the statistical approach is mainly that it is feasible. It is usually possible to find sample weather and yield data from a desired geographical region, and it is not very difficult to gain access to a regression routine that requires only minimal programming efforts. Some of the disadvantages of the statistical approach are

1. The investigator nearly always has to use historical yield and weather data that were collected for some other purpose.
2. If the sample yield and weather data have been collected from a carefully documented research plot, they can be regarded as precise measurements. If these data are from large production areas (the equivalent of a U.S. county or larger) they are nearly always estimates rather than measurements and thus are subject to sampling error (which gets larger as the sample area gets smaller).
3. Multicollinearity of the "independent" weather variables in the model results in subtle but serious problems in testing hypotheses on the regression coefficients and in applying the model in a predictive mode. This is a fancy way of saying that there aren't very many "independent" meteorological variables.
4. The problem of specifying the impact of technological change for the historical sample of yield data and projecting this trend into the future is most troublesome. If this is not handled properly, the portion of the model related to meteorologically-induced variability will be weakened. (This problem also exists in causal models.)

The reader not familiar with the statistical approach is referred to the papers by Thompson[5-7] and by Changnon and Neill.[1]

Technology Trend Function in Crop Yield Models

The wheat yield data series for Oklahoma is shown in Figure 1. This is typical of yield data series for other regions and other crops. Most of these yield data series show a comparatively flat trend for the first few decades, with a substantial trend toward higher yield values in the most recent 2 or 3 decades. It is possible to make a plausible list of the mechanisms (which are lumped together under the term "technology") that have caused the recent increases. These would include better seed, more fertilizer, use of insecticides and herbicides, substitution of mechanical energy for animal and human energy, better machinery, better management, etc. A rational weather/crop yield model should theoretically include these factors as specified variables. Most models do not. Instead, they use "time" or "year" as a surrogate variable.

In Figure 2, a piece-wise time trend line has been fitted to the yield series, with a break in the trend line at year 1955. This is consistent with the time of introduction of new wheat varieties and the use of increased amounts of chemical fertilizer. But in an

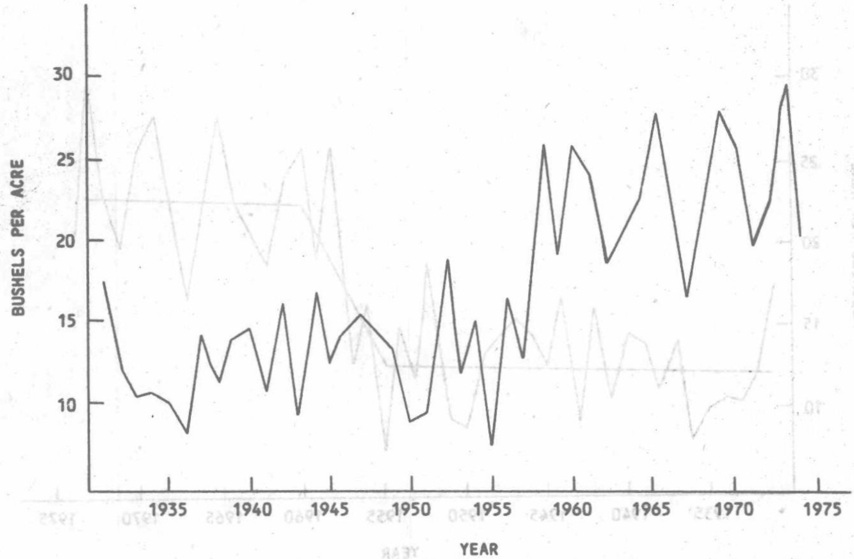

FIGURE 1. Oklahoma wheat yields (raw data).

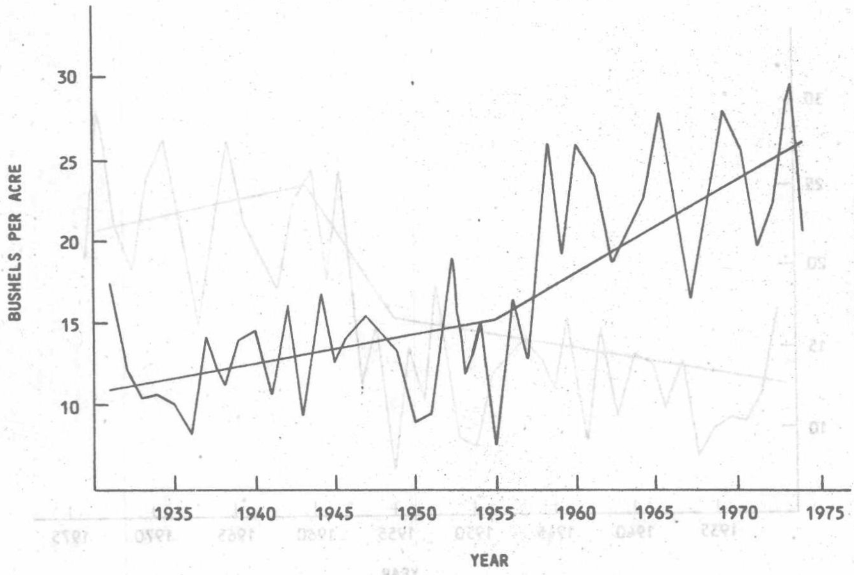

FIGURE 2. Oklahoma wheat yields, technological change (Model 1).

equally plausible model (Figure 3), the investigator thought it reasonable that the piecewise time trend line be fitted to the data with discontinuities at years 1955 and 1960. In Figure 4, the trend line coefficients and the meteorological coefficients were estimated concurrently. This model is of the form

$$\hat{Y} - \overline{Y} = f(\text{year}) + g(\text{weather})$$

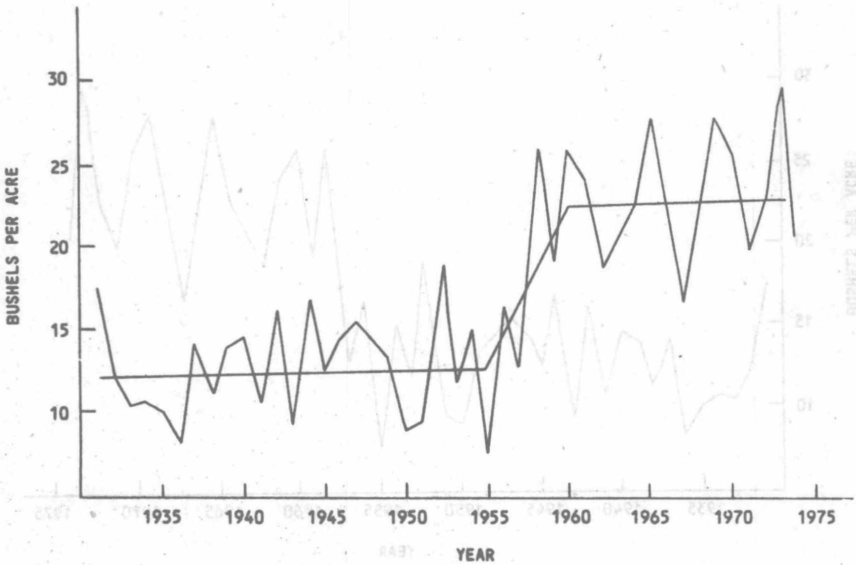

FIGURE 3. Oklahoma wheat yields, technological change (Model 2).

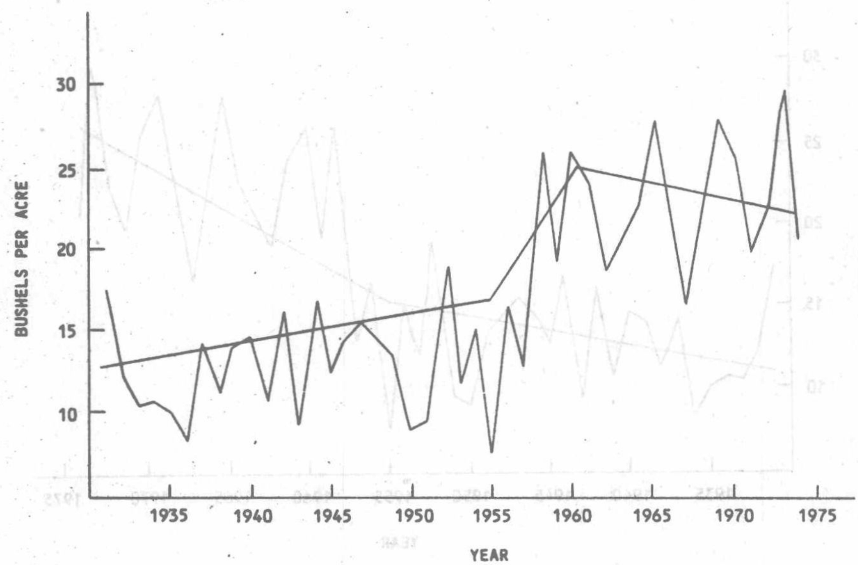

FIGURE 4. Oklahoma wheat yields, technological change (Model 3).

where g (weather) is evaluated as a nonlinear function of deviations from mean weather values. We are using this latter specification of the technology trend function in operational work in progress at the Center for Climatic and Environmental Assessment in Columbia, Missouri.