Response Functions For Nontraditional Inputs In Agriculture

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Abstract
As part of the restructured regional research program of the U.S. Department of Agriculture and the Land-Grant Universities, a research strategy committee (NCR-113) was formed in 1978 to identify new research thrusts in the area of farm firm management and finance. At the first meeting in April, 1979, a number of possible areas for additional research activity or new thrusts were identified. One area identified was that of the development and utilization of "new" inputs in agriculture and the estimation of response functions for these inputs...

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RESPONSE FUNCTIONS FOR NONTRADITIONAL INPUTS IN AGRICULTURE

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Preface

As part of the restructured regional research program of the U.S. Department of Agriculture and the Land-Grant Universities, a research strategy committee (NCR-113) was formed in 1978 to identify new research thrusts in the area of farm firm management and finance. At the first meeting in April, 1979, a number of possible areas for additional research activity or new thrusts were identified. One area identified was that of the development and utilization of "new" inputs in agriculture and the estimation of response functions for these inputs.

To focus the discussion more specifically on the issues in this area, two papers were commissioned and are published herein. The first paper by Michael D. Boehlje discusses the need for more empirical work in estimating response functions for these "new" inputs and some of the problems encountered in completing research in this area. The second paper by Donald Collins and Jeffrey Apland discusses research being completed by the private sector as part of the process of developing and merchandising chemical pesticides.

These papers are published with the intent of stimulating discussion and dialogue on the desirability of implementing research in this area.

Michael Boehlje, Chairman
NCR-113, Farm and Financial Management
RESPONSE FUNCTIONS FOR NONTRADITIONAL INPUTS*

by Michael D. Boehlje**

Introduction

With technological advance in agriculture has come new inputs and products. Chemical pesticides have partially replaced mechanical tillage in weed and insect control. Feed additives such as sulpha-based drugs and antibiotics are commonly used in livestock rations to improve feed efficiency and animal performance. The role of micro-nutrients such as sulfur, zinc, selenium, etc., in crop production has become more important with increased understanding of the biological and physiological determinants of growth. Some of these "new" or nontraditional inputs have implications beyond their impacts on the efficiency of crop and livestock production—their utilization has social as well as private impacts. In some sense such inputs as pesticides and feed additives have response functions characterized by multiple outputs—the traditional output is evidenced by increased crop yield or livestock production, but the social output in terms of residues that may result in environmental degradation cannot be easily ignored.

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Response Functions

Little data or empirical analyses are available indicating the response functions for many of these nontraditional inputs. For example, a common statement concerning pesticide applications is to utilize a "recommended rate." This recommended rate is the rate at which "adequate" control of the pests can be expected. Little data is available suggesting the expected control with application rates other than the "recommended rate." The shape of the response function between the two extreme points of no application and the "recommended rate" (or in fact, beyond the "recommended rate") is virtually unknown. In economic terms, such a description of the physical response function leads to corner solutions for individual firms, i.e., either the recommended rate of the particular input is utilized or none at all. An optimal intermediate level to apply is difficult to identify; nor is it possible to identify changes in the optimal quantity with changes in relative prices of the inputs.

From a social perspective, the lack of a production response function with respect to inputs that have the potential for environmental degradation may be partially responsible for the "all or nothing" syndrome evidenced by such public policy as the zero tolerance of the Delaney amendment. When only the two end points of a potential response function are available, it becomes difficult for agricultural scientists or policy makers to suggest the potential reduction in production which would result from a 25, 50, or 75 percent reduction in input utilization from the recommended rate. For example, reducing herbicide
utilization by 25 percent could result in only a small reduction in corn yields, but a relatively large reduction in chemical residues. Important results such as these cannot be known when only the yield response at the recommended rate is available. Yet, quantifying this trade-off would seem important in policy decisions concerning regulations on the use of such inputs in agriculture.

Some Illustrations

Pesticides

Herbicides and insecticides are a predominant input in crop production. Surveys in Iowa indicate that a large proportion of total crop acreage is treated with some form of chemical pesticide. Chemical companies that produce the various pesticide products as well as extension agronomists, entomologists and weed specialists have developed recommendations concerning the appropriate rates of application of the various pesticides to control selected pests. Most producers seem to follow these recommended rates, but heavier applications may occur in some instances with particularly persistent pests. Because of concerns about water quality and the potential environmental degradation that may occur if certain agricultural pesticides enter the nation's waterways, a number of state and federal agencies are discussing restrictions and controls on various pesticides. In fact, the use of some pesticides such as heptachlor and chlorodane has already been severely restricted.

As part of an attempt to evaluate the impact of reducing water pollution from agricultural chemicals (as well as sediment), scientists
at Iowa State University were asked to determine the impact on individual farms of reduced application rates for herbicides and insecticides. Entomologists and agronomists participating in the project indicated that such estimates were difficult, if not impossible, to obtain since experiments using various rates of application of the chemicals had not been performed by the Land Grant—USDA research complex. Further discussion suggested that such research data were not available to the public or public research agencies from the manufacturers of the products. Consequently, only judgmental assessments were available to determine the potential yield response with application rates of 1/2 and 3/4 of the recommended rate for the particular pesticide. This example clearly illustrates the dilemma encountered in making recommendations to individual producers and/or for public policy choices concerning the utilization of a particular input when production response data are unavailable.

Feed Additives and Antibiotics

Feed additives such as sulpha compounds in swine production, and Rumensin, MGA and Ral-gro in cattle production (and Stilbestrol prior to its being banned as a feed additive) as well as therapeutic levels of antibiotics in both cattle and hog rations have been an integral dimension of the livestock industry in recent years. Such additives have contributed significantly to the efficiency of producing livestock products, yet questions have been raised recently concerning residues of these feed additives in livestock carcasses and the impact of such residues on human health and/or the effectiveness of the use of similar
drugs in combating human diseases. Recent public discussions concerning sulpha residues found in hog carcasses have dramatized the public concern. Although the discussion of feeding therapeutic levels of antibiotics has not received as much public exposure, scientists in the nutrition and veterinary medicine disciplines have raised questions concerning the public health dimensions of using such additives.

Research results are readily available to document the efficiency and productivity impacts of using such additives at the "recommended rate" compared to not using such additives. But little, if any, research is available indicating the potential response from intermediate levels of utilization. Apparently, as with pesticides, a physical threshold concept is utilized in determining "recommended rates" of these additives. This physical threshold concept implies that utilization of the additive or input below a particular level will result in no response, whereas utilization at a particular level (the "recommended rate") will result in the maximum response attainable. Even if economic logic and relative prices were to suggest that only the two extremes were relevant and that a corner solution was reasonable from the viewpoint of an individual producer, the social concerns about such inputs again suggest that response function information could be valuable to determine the trade-offs between reduced productivity and lower residue levels if utilization rates were reduced.

Crop Residues and Animal Wastes

Substantial interest exists in using crop residues and animal
wastes as feed inputs for animal production and as energy inputs. Research at various universities indicates the nutritional value of such residue materials and numerous feeding trials and experiments are currently underway. However, the future of feeding animal wastes to livestock is clouded by the uncertainty surrounding the position of the Food and Drug Administration (FDA) concerning the use of such material in livestock rations. In particular, FDA and some public health officials have raised questions concerning the concentration of feed additives and antibiotics in livestock wastes and the implications concerning human health if such waste material is refed to livestock. Furthermore, from an individual producer’s perspective, preliminary research suggests that the substitution ratio of such waste materials for traditional inputs in livestock rations is not constant and that only limited quantities can be utilized because of palatability and digestion constraints. Yet, explicit response function estimates for these inputs is not readily available, and it is not clear that current experiments are based on appropriate experimental designs to estimate such response functions.

Agricultural residues can be used as energy inputs using existing technology. Further research is developing new technologies for using crop residues in direct combustion and in the manufacture of liquid fuels. Many policy issues surround this energy resource, including the economic viability of conversion, the effects of crop residue removal on soil erosion, and the environmental benefits of blending crop residue with high sulfur coal as a means of reducing emissions from coal burning plants. Data describing these energy technologies would
facilitate the necessary economic analyses of these policy issues.

Other Examples

Other examples of inputs that are being utilized in agriculture without adequate production response data include micronutrients in crop and livestock production. Furthermore, various methods of using traditional inputs such as foliar applications of plant nutrients, utilization of liquid versus dry versus anhydrous ammonia forms of nitrogen, and the feeding of "protected protein" to ruminant animals merit attempts to obtain production response relationships. These examples are used only to illustrate the need for further research and documentation of response functions for inputs used in modern agriculture.

Estimation Issues

If response functions are to be estimated for these "nontraditional" inputs, a number of estimation and measurement issues must be adequately answered to obtain acceptable empirical results.

Experimental Design

One of the key determinants of whether or not the entire response function (rather than just the end points) can be estimated is the experimental design used in structuring the physical experiments. At least two dimensions of experimental design are important and require thorough discussion among physical scientists, economists, and statisticians. The first dimension is that of structuring the experiment in such a fashion as to "fix" the "other" variables so that the production response can, in fact, be attributable to the controlled input. The
second issue involves the levels of utilization of the controlled input. Sufficient observations must be obtained at intermediate levels of utilization between the two endpoints of no utilization and the "recommended rate" to give a reasonable estimate of the true response function. Such experiments may require additional resources because the number of application rates and thus trials will increase significantly compared to the common approach now used of comparing the recommended rate to no application or utilization of the input.

Definition of Output

In addition to the traditional measurement of output in terms of yield in crop production and rate of gain or feed efficiency in livestock production, it will become increasingly important to measure other outputs in production response research. Specifically, measurement of the residues that exist if, for example, various levels of feed additives are used in a ration or different levels of pesticides are applied in crop production will be necessary. These residues are no less an output of the production process than the traditional crop or livestock product. Separate response functions for the primary product and the residue may be estimated using traditional estimation procedures, or such procedures as conical correlation might be utilized to estimate the joint response function for various outputs as a function of the nontraditional and other inputs.

Timing of Application or Utilization

Experience with the use of fertilizer and irrigation water in crop production suggests that time of application is an important dimension
of response function analysis. This dimension of timing is equally, if not more, important in analyzing response functions for such non-traditional inputs as pesticides, feed additives and antibiotics and new technologies such as foliar fertilization. The timing of application not only influences the production response in terms of crop yield and livestock efficiency, but it also influences the residue response function as well, particularly in the case of pesticides and feed additives. Physical experiments that do not include variations in time of application will not only give inaccurate estimates of the product response function, but possibly more importantly, erroneous measurement of the residue response function.

**Measurement**

New dimensions and procedures in the measurement of inputs and outputs may be required in determining response functions for non-traditional as well as traditional inputs. For example, the net energy system is considered by many to be preferable to total digestable nutrients (TDN) as a method of measuring the energy input from various feedstuffs in livestock production.\(^{15}\) Furthermore, some researchers prefer the metabolizable protein system to the digestable protein system in measuring the protein content of feed ingredients and the production response expected.\(^{16}\) With an improved understanding of the biological and physiological processes underlying plant and animal growth, improved means of measuring and quantifying inputs and outputs can be expected. Production research must incorporate these new measurement dimensions to adequately quantify response functions.
Conclusion

Our purpose here was to briefly review the need for improved response function data and relationships for nontraditional inputs. A number of examples to illustrate the argument were presented, and some of the important empirical estimation issues were briefly identified. Attempts to quantify these response functions will require joint projects involving physical scientists, agricultural economists, and statisticians. For many of these inputs, at least two response functions are of interest, the production response function indicating the quantity of an economic "good" that can be expected with various levels of application of the input, and a residue response function indicating the quantity of a public "bad" that might be expected. Estimating response functions for these inputs will be useful in evaluating both micro, farm level management decisions as well as policy decisions concerning the regulation and control of their use.
Footnotes


2/ The Food Additive Amendment (Public Law 95-929).


RESEARCH IN THE TECHNOLOGY OF NONTRADITIONAL INPUTS: THE CASE OF COMMERCIAL DEVELOPMENT OF CHEMICAL PESTICIDES*

by

Donald Collins and Jeffrey Apland**

Agricultural production economists must evaluate resource allocations within an intricate environment of available technologies. Although the necessary link between production economics and the physical and biological sciences is clear, the work of economists and that of technical scientists has not been well coordinated, and in fact has been incompatible in some instances. In a 1961 monograph, Heady and Dillon pointed out that physical and biological research in agriculture had fallen short of the needs of production economists. They cited reasons for these shortcomings and explained the importance of the development of technical data for estimating production functions. In many technical areas (such as the yield response to fertilizer and animal feed rationing), needed technical data have long since been available. And the agricultural economics literature contains abundant evidence of the usefulness of this data in prescriptive and descriptive economic analyses. However, with respect to what might be called "nontraditional" inputs, many technical data needs still exist.

Agricultural technology is continuously growing and with it, the need for economic research. As such, production economists are faced with

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* This paper is based primarily upon a presentation by Donald M. Collins to the NCR-113 Committee at Kansas City, Missouri in April, 1980, and the discussion by the committee which followed.

** Donald Collins is Director of Product Development, Monsanto, and Jeffrey Apland is Assistant Professor, Department of Agricultural Economics, University of Kentucky.
The growing needs for production function data (Boehlje). The nontraditional inputs which embody the new agricultural technologies include feed additives, animal drugs, agricultural wastes and residues, and pesticides.

The purpose of this paper is to summarize one component of technical research involved with nontraditional inputs. Specifically, the commercial research carried out in the development of chemical pesticides will be described and then discussed within the scope of overall economic data needs. The authors hope that this paper will help to illustrate the nature of on-going research in the area of nontraditional inputs and help to point out future research needs.

Development of a Commercial Pesticide

The research involved in the development of a commercial pesticide generates a wealth of data describing the technical relationships between this nontraditional input and the agricultural pests it is designed to control. Additionally, much is learned regarding environmental impacts which could be useful in the analysis of externalities related to pesticide application. Perhaps the best way to gain an appreciation of exactly what is involved in the development and commercialization of a new pesticide is to trace the history of a compound nearing registration. Basically, the process can be laid out in a seven year chronology.

Product synthesizing and screening take place in the first year. Two methods are used to identify and isolate those chemical products which may be applicable to today's agriculture: random screening and directed synthesis. Across the agricultural chemical industry, an average of between 10,000 and 12,000 compounds are examined by one of
these methods before one commercial product emerges.

Random screening is an approach based on experiment and observation. Chemicals from a variety of sources are put through initial screening tests to determine general areas of activity—herbicidal as well as insecticidal, fungicidal and acaracidal.

Directed synthesis, in contrast, is an approach which has been much more successful. Researchers following this method are guided by a body of theory which permits them to isolate, from the billions of possible compounds, those few which will be active on pests and yet be selectively safe for crops. Synthesizing and screening are conducted in a laboratory greenhouse where field conditions are duplicated as closely as possible. If the appropriate results are observed in the primary screening, the material is then taken into secondary screening, also in the greenhouse. Here the field of compounds is narrowed to several hundred chemicals selected for pesticidal activity. The compound is then applied at different chemical rates to target species in various stages of growth to determine the level of crop sensitivity. Initial toxicology tests are also carried out at this stage to assure the researchers that the potential products are not toxic.

In the second year of product development research, the compounds which survive lab screening are tested under field conditions. These initial field tests are on small plots replicated to give the researchers a better fix on how effective the products perform under field conditions. During this first year of field research, the chemicals are tested on a wide range of crops, at a variety of rates; and in pre-emergence, pre-plant incorporated and post-emergence applications.
The standard procedure for third-year experimental compounds is to repeat the previous year's test work to verify the initial observations. Along these lines, efforts continue on product synthesis for expanded field evaluations and on the development of commercially acceptable pesticide formulations. A pilot plant is developed for production of the pesticide at this stage, also. Toxicology work and other long-term tests needed to satisfy the Environmental Protection Agency registration requirements are initiated. Moreover, analytical methods to measure chemical residues in crops and to trace the compounds in the environment are developed. At this stage, the product is tested in key geographic areas throughout the United States and other countries to get broader experience with the product. Other crops are also screened. U. S. Department of Agriculture and other research groups outside of the company are allocated material for their independent assessment. At the end of the season, results from around the world come in on the new pesticide.

The fourth year is one for the initiation and continuation of studies needed to fulfill registration requirements for the United States in the areas of crop and soil residues, field performance evaluations and environmental and toxicological studies. An experimental use permit is normally granted by the EPA in year five. This permits continued widespread testing throughout the country to further refine the product's activity on various pests, establish optimum use rates and to test the pesticide under a wide variety of environmental and cropping conditions.

The expected result after six years of testing is, of course, registration of the new chemical in the United States for those uses given on the label. Once registration is granted for a particular crop,
however, the work is not over. The sales department is then given the job of recouping the company's investment and turning a profit within the 17 year life of the patent, which in many cases is half depleted by the time registration is granted.

For the ultimate consumer of the product—the grower—the availability of a new pesticide can mean many things. To some it may only be a new tool with which to fight old problems. For others it may mean an opportunity to change crop management practices drastically so as to take advantage of the compound's unique properties.

**Use of the Data**

Technical data generated in product development such as that described in the previous section can be used for the estimation of response functions in economic analyses. Important technical relationships can be derived from the experiments which consider pest control at various application rates. Further, data on the timing of application with respect to the stage of growth of the crop and the pest population provide needed management information. Experiments replicated on a variety of soil types and geographic locations provide necessary observations for a variety of levels of uncontrolled variables. The experimental design used in commercial pesticide development research could provide the data needed to estimate the variability associated with various pest control measures, as well. Technical variability is, of course, an important source of risk in farming. From the standpoint of developing overall production functions for pesticide use, the product research studies provides one half of the necessary data; the impacts of the chemical on
the pest population. Further technical research is necessary to link the 
pesticide use to farm output through the effects of the pest on yields.

A few comments regarding technical research and analytical problems 
in response function estimation are in order at this point. The 
ultimate goal of production function (or technical response function) 
estimation is to derive production surfaces to which economic criteria 
can be applied for deriving economically efficient resource allocations. 
Toward this end, the technical research should provide observations on 
variables within the full range of economic relevance. If during product 
development, certain noneconomic guidelines are used (perhaps industry 
standards or government regulations) the technical data which evolve will 
implicitly carry the imposed restrictions. A simple example will serve 
to illustrate this point.

Suppose in the early stages of product development, efficacy guide- 
lines require that the chemical application level provide at least 80% 
control of the pest. Further technical data derived in the product 
research, then, will represent only a portion of what might be the 
economically relevant technical relationships. Guidelines of this sort 
may have evolved with a consideration of economic relationships; however, 
in a changing economic environment, such limitations should be applied with 
care. This point may be of particular importance when environmental 
regulations are being studied with technical data to which environmental 
standards have been pre-imposed.
Concluding Remarks on the Economics of Pesticide Use

The emphasis of this paper has been an economic perspective of technical research on a nontraditional agricultural input: pesticides. The analytical techniques which have been applied to economic problems of pesticide use may provide an appropriate closing theme. Many of the conventional production economics approaches are applicable to pest problems and need not be mentioned. However, a brief statement regarding more contemporary analytical methods is in order.

Depending upon the variability of such uncontrolled variables as rainfall, temperature, pest population, etc., the response of the pest population to pest management practices (the "kill function") and, in turn, the yield response to the pest population (the "damage function") may be uncertain. This being the case, an analysis framework that includes risk and uncertainty may be needed. Along these lines, statistical tools such as Bayesian analysis may be applicable to the study of uncertainty in pest management problems when relevant additional information needs to be incorporated into the decisions. A conceptual model has been presented by Feder in which uncertainty is considered in the level of pest damage, the size of the pest population and in the level of control associated with the use of a pesticide. He also addresses the economic issues of improved information regarding pesticide use and innovation of new pesticide technologies.

The chapter by Headley in Introduction to Insect Pest Management (see References) develops pest management concepts beginning with a naive model demonstrating marginality in the determination of the economically optimal level of pesticide use. Headley proceeds by introducing uncertainty and dynamics into the model.
The pest-pesticide-crop system is physically and biologically complex. As such, contemporary quantitative methods may be needed to properly model pesticide technologies. The use of simulation has been used to model the interactions of pest and crop subsystems in order to capture the technical response of output to pesticide use (Talpaz, et al.; and Reichelderfer and Bender). The dynamics of pesticide use is important in pest management and is incorporated into the simulation studies cited. Among the dynamic relationships considered are timing and frequency of chemical applications. These relationships are intimately tied to pest population growth and the interaction of the pest with the crop at various stages of crop growth. These more sophisticated economic evaluation methodologies, however, still require basic data on response functions that can only be obtained from physical and biological experiments.

Summary

Economic issues in chemical pesticide use abound. And the study of these issues requires a broad array of technological research. The mutual needs and interdependencies of economics and the technical sciences should serve as a guide for future pesticide research. With respect to the research issues related to pesticide use, the following points can be made:

1. Technical data in the area of nontraditional inputs often have limitations similar to those which, in the past, existed for what have come to be considered as traditional agricultural inputs.

2. A variety of technical data, which could be used in economic analyses, is generated in commercial pesticide development research.
3. Guidelines which are used in technical research should be viewed critically with respect to the restrictions they may impose on economic analyses which will rely upon the technical data.

4. Analytical tools are available for studying the relevant issues surrounding the use of chemical pesticides. It is important for biological, physical and economic scientists to be cognizant of the types of information needed to use these tools and to apply them in a manner consistent with the overall information needs of industry and society.
References


