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Research Productivity of the State Agricultural Experiment Station System: Measured by Scientific Publication Output

G.W. Salisbury

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**Bulletin 762
Agricultural Experiment Station
College of Agriculture
University of Illinois at Urbana-Champaign**

ACKNOWLEDGMENTS

The investigations reported here on the scientific publication output of agricultural experiment stations in the United States were initiated as early as 1948 when the author as head of the Department of Dairy Science began keeping score on the progress of that one department. The effort was expanded to include the research productivity of all the domestic animal sciences in academe when the author was a member of the Agricultural Panel of President J. F. Kennedy's Science Advisory Committee, 1961-1963. It was expanded further to include all major subjects of agricultural research under Hatch Project 1-320, Research Productivity—A Study in Research Management, 1971-1977, when the author served as director of the Illinois Agricultural Experiment Station, 1969-1978. The detailed analysis of the Illinois Agricultural Experiment Station records was completed after retirement.

Many people aided the author in the course of the acquisition of these data and their statistical analyses. It is believed that in most instances appreciation for that aid was expressed at the time it was provided. Those deserving special mention include R. J. Miller, director of the Idaho Agricultural Experiment Station who as associate director of the Illinois Agricultural Experiment Station helped extend the study beyond the limits of animal agriculture; F. M. Wilkens, who organized the details of recording the page-by-page analysis of the 31,911 papers constituting the major original contribution of this report; C. R. Anderson and S. L. Warren, who supervised the statistical analysis of the data, the first as the explorer of its parameters and the second who placed the capstone; and J. H. Olson, who in 1977-78 made the first attempt to gather the findings of the several studies together as a coordinated whole.

G. W. Salisbury

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ABSTRACT

Three studies are reported of the scientific publication output of U.S. agricultural experiment station scientists for the period 1945 through 1978. The first study dealt with the 1945-1975 fiscal-year sequence of reports by the stations to the U.S. Department of Agriculture of their annual publication of technical journal articles.

The second analysis was of three different three-year series of publications by agricultural scientists in selected peer-edited agricultural science journals. The first subset for the calendar years 1958-1960 dealt solely with the number of publications in the subject matter of domestic animal research. The second for calendar years 1965-1967 dealt with the number of domestic animal research publications and also included a survey of the opinions of 85 scientists in the field of the relative ranking of the stations of the 50 states. The agreement between the station rank order by actual count of publications and the collective opinions of scientists of the relative rank of the stations was high. The third subset in this study was of full-length scientific papers appearing in 66 selected peer-edited scientific journals published during the calendar years 1967-1969 for ten different agricultural subject matters.

The third study dealt in detail with the 30-year publication record (1948-1978) of the Illinois Agricultural Experiment Station by departments and research units. Throughout all of these investigations some corollary evidence on total research funding and staff size of the departments, research units, or stations was available for study in relation to publication output.

Statistical studies indicated that there exist real differences in the publication output among the states, with relative funding and staff size the important covariables. The rank order of the top ten stations changed when staff size and dollar funding were held statistically constant.

The Illinois station ranked at about the center within the first ten state stations however the calculations were made. Within the Illinois station, the differences in publication output for the several units were largely determined by the input of constant-value dollars and the number of scientists.

The publication tradition and behavioral patterns of the several Illinois subject matter fields differed. The proportion of their total publications published in peer-edited journals varied widely among units but changed little with time, and the Illinois behavior seemed not to differ from that of counterparts elsewhere.

The rank order of the Illinois units in publication output varied with the measure of output used, total station-reported publications or peer-edited ones, but the magnitudes of the inputs into the units, numbers of senior scientists and number of dollars (actual or of calculated constant value) invested, were greater influences on the numbers of publications resulting and the rank order.

The Illinois station has performed its research function as measured by the standards of this research well above the mean of its U.S. counterparts. The question occurs as to why this should be the case. Aside

from the observation that the senior staff is of more than average competence and, as individuals, are loyal and like what they do, there are no data to test the point. There is evidence that their peak efficiency has been reached and that the reduced public investment in constant-value dollars apparent in the past few bienniums has already resulted in a decrease in the output of the products of research the Illinois Agricultural Experiment Station was created to provide.

CONTENTS

The Agricultural Research System in the United States	8
Organization of Research at the Illinois Station	11
Scientific Publications as a Measure of Research Productivity	13
Source of National Data on Publications Output	14
Study I: A Review of Station Publication Numbers Reported by OES and CSRS	14
Study II: Peer-Edited Journal Articles	19
Study IIa: Journal Articles — Animal Agriculture, 1958-1960	20
Study IIb: Journal Articles and Opinion Survey — Animal Agriculture, 1965-1967	20
Study IIc: Full-Length Journal Articles — Ten Agricultural Subject Matters, 1967-1969	24
Illinois Rank by Subject Matter Areas — Peer-Edited Journals	25
Study III: The Thirty-Year Research Productivity of the Illinois Station, Fiscal Years 1949-1978	30
Variations in the Nature of Agricultural Research	31
Number of Staff	33
Financial Support	33
Number of Publications	35
Publications per Scientist	35
Publications in Relation to Operating Investment in Research	38
Corollary Changes Within Science as an Enterprise	40
Statistical Treatments of the Data	42
Time Trends in the Efficiency of the Illinois Station's Publication Output	45
Outlook for the Future Publication Productivity of Agricultural Scientists	47
Dependence of Publication Output on Dollar Investments	48
Variations in Level of Investment in Agricultural Research	49
Federal: Hatch and McIntire-Stennis	49
State	50
Intrainstitutional Allocation of Funds	50

Public Examination Necessary	51
Agricultural Research Necessary to National Welfare	52
Lessons From the Illinois Study	52
Publication Records as Indicative of Benefits From Research	54
Public Examination — Invasion of Privacy?	56
The Problem for the Public	57
References Cited	58
Appendix: Raw Data for Study IIc	60
Publications in 66 Peer-Edited Journals, by Subject Matter for All Stations, 1967-1969	61
Peer-Edited Journals Used in Study IIc	62

Research Productivity of the State Agricultural Experiment Station System: Measured by Scientific Publication Output

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This appraisal of research productivity is intended as an accountability report to the public of use since 1945 of tax dollars by the Illinois and other state agricultural experiment stations in the continuous endeavor to provide a technology insuring that adequate food and fiber can be supplied by all of agriculture. The report deals solely with making public the results of the research investigations that the public sponsors. It leaves to others the assay of benefits to the public from the development and application of the resulting technology.

The agricultural research system in the United States and its corollary system for informing agricultural producers and others who use agricultural information of its findings are probably the best combination in the world for the purpose. It would be an enormous task to review the accomplishments of that research, but serious students of the situation agree that the returns from such research have exceeded by many times the amounts invested in it and that huge benefits to all parts of society have accrued from the work. The achievements of the Illinois station alone would make an impressive list.

The purpose of agricultural research has been to improve the technology used in the production, harvesting, processing, marketing, delivery, and utilization of food and fiber crops to the benefit of rural life and the economic welfare of the consumer. Since the establishment in 1875 of the first state agricultural experiment station in New Haven, Connecticut, the industrialization of America and the expansion of its economic system have profoundly changed commercial agriculture and its role in America. Today, it not only produces sufficient basic food and fiber items to meet our own needs but it is a major producer of exports, partially offsetting the enormous negative trade balance for foreign oil.

Because the research is designed for such a practical purpose, the results of research from the beginning of the system have tended to be published in journals and other sources that are readily available to the

industry (20*), resulting in some isolation from a readership by other scientists in biology and medicine (23). Some of the societies or associations designed for exchange of information and publication of research with agricultural crops and animal species have existed for years and antedate many of the present more commonly recognized scientific journals. There has resulted an enormous, basically rich scientific literature largely unexplored by scientists outside the field.

Although the overall utilitarian quality of the work has been recognized, there have been few techniques available for measuring the relative effectiveness and efficiency of individual elements of the research establishment. It is relatively easy to evaluate the performance of an individual scientist, and it is easy also to identify scientific "stars" in an organization. But administrators have found it more difficult to measure the quality of their staff against that of others doing similar work.

One practical measure that can be used is the publication of scientific papers. Publications are usually the only tangible and readily quantifiable immediate products of research. Acceptance of an article for publication in a journal, especially a journal published by a scientific society or association of scientists, usually involves careful review of its scientific merit by a committee of peers. This kind of peer review sets a floor for the scientific merits, techniques, and objectivity of the work reported in the paper, although it cannot vouch for the accuracy of the data presented or for the validity of the conclusions drawn.

Publication of scientific papers is the measure used in the studies reported here of research productivity and efficiency at the Illinois Agricultural Experiment Station. Two of the studies compare Illinois with other experiment stations and one is internal to the Illinois station.

The Agricultural Research System in the United States

The Illinois Agricultural Experiment Station is a part of a system unique in the world for generating and distributing new knowledge about agriculture and rural life. Every social and political system through history has given some attention to agriculture and food and to scientific study and application of new knowledge to improve and maintain the food supply. Other nations preceded the United States in setting up publicly supported experiment stations and others established federal bureaucracies to deal with agriculture, but no nation put them together with a formal and informal educational system in such a manner and

* All such numbers refer to "References Cited," later in this publication.

with such resources as the United States to generate opportunities for the common man to own land and provide him the ability to farm it. The system was begun by Congress during the Civil War and expanded with the cooperation of state legislatures (13). Each unit of the system was established in response to different priorities set by society as it grew. During the twentieth century we have seen increasing research by industries related to agriculture, often emphasizing the development of an idea for operational production systems and use of their own products.

The Land-Grant System. In 1862 Congress through the Morrill Act assigned ownership of government land to the states to develop colleges of agriculture and mechanic arts. The University of Illinois was established under this act on March 2, 1868.

U.S. Department of Agriculture. The present USDA grew out of an agency established in 1862 to work for the improvement of agriculture throughout the country. Its functions have been extremely varied over the years, but it has contributed to the development of research through research centers, regional laboratories, and cooperation with state and other agencies.

State Agricultural Experiment Stations. The Hatch Act in 1887 established agricultural experiment stations at the land-grant colleges. At that time few agriculturists were familiar with the principles of scientific agriculture, and the new land-grant schools were not yet equipped to make substantial contributions to agricultural science (23). The Hatch Act was passed to educate and equip a corps of scientists to learn what to teach about agriculture and rural life (13).

On its establishment in 1868, the University of Illinois was mandated by the Illinois legislature to conduct research with and for farmers. Its administrators became leaders in the national movement to establish in each state some formal organization for agricultural research. The Illinois Agricultural Experiment Station was formally established at the University of Illinois on March 21, 1888, soon after the Congress passed the Hatch Act. Publicly supported research is conducted by it and 51 other state stations (two states have two each), by stations in Puerto Rico, the Virgin Islands, Guam, and the District of Columbia, by the U.S. Department of Agriculture, and by other non-land-grant universities.

Under the Hatch Act and other acts passed by Congress relating to agricultural research, the federal government supplies some money to each state for agricultural research, of which any amount above a spec-

ified minimum must be offset dollar for dollar by state funding. In Illinois approximately 35 percent of the funds expended by the experiment station comes from federal appropriations (of which about two-thirds are Hatch and McIntire-Stennis allocations), and nearly half from the state of Illinois. The balance comes from gifts, grants, contracts, and other sources.

Extension Service. Unlike most industrial technology, the technology that supports agricultural production often must be tailored to the specific needs of individual farmers with unique production circumstances and capabilities. Such tailored technology must come from principles developed by research done in the regions and states where it is to be used. That is one of the great strengths of the state agricultural experiment station system.

Although not responsible for conducting research, the cooperative extension services have been a key link in getting the results of research to those who can use them and in the sort of tailored form needed by individual farmers. In 1914 Congress enacted the Smith-Lever Act, which established extension services in agriculture and home economics at each state land-grant college of agriculture. Extension people gather research results, deliver the results to the people who can use them, and often help the people organize to put them to use. They also bring back problems from the field for researchers to work on. At Illinois researchers often take part in extension activities and report their work in a down-to-earth form to those who can apply their results. Some primarily extension faculty members hold part-time appointments in the agricultural experiment station.

Cooperative Research. All states, including Illinois, do much research in cooperation with other agencies. The states of the North Central Region, of which Illinois is a member, and the U.S. Department of Agriculture cooperate in regional research, examining problems for which a multi-state basis can give a better answer. In fact, Congress stipulated in 1955 that above an amount permitted originally by the act of 1946 that initiated regional research, up to 25 percent of all increases in Hatch funding beyond that date should be expended in regional research. The Illinois station also cooperates with agricultural industries, which support some of the research by unrestricted gifts, by contract, or by grants in support of research proposed by a station investigator. Other state agencies, like the Illinois Department of Agriculture and the Illinois Natural History Survey, also work with the Illinois Agricultural Experiment Station.

Organization of Research at the Illinois Station

The Agricultural Experiment Station is one of four major divisions of the University of Illinois at Urbana-Champaign College of Agriculture. The director's office coordinates all matters relating to the research of the college, prepares budgets, maintains liaison with the U.S. Department of Agriculture and with other administrative units, and makes reports of its activities and progress.

The research is done in twelve research units, all but two of which are in the College of Agriculture. Scientists are staff members of their own particular unit. The units include:

- Department of Agricultural Economics
- Department of Agricultural Engineering
- Agricultural Entomology, a part of the Illinois Natural History Survey but receiving some Agricultural Experiment Station support
- Department of Agronomy
- Department of Animal Science
- Department of Dairy Science
- Department of Food Science
- Department of Forestry
- Department of Horticulture
- Department of Plant Pathology
- School of Human Resources and Family Studies (formerly known as the Department of Home Economics)
- Veterinary Research, an organization in the College of Veterinary Medicine receiving support for certain research functions from the Agricultural Experiment Station

Each funded research and the experiments, investigations, or surveys undertaken for it are done on a project basis. The proposal for research originates with a principal investigator who, from his or her background and experience and his or her interactions with other scientists and colleagues in the extension service, decides that a particular problem is worth pursuing. Procedures, approvals, assignment of funding, and business and reporting operations conform to long-established requirements of the University of Illinois, the Illinois state government, the wishes of the grantor if private funds are involved, and the U.S. government if its funds are to be used. Federal funding may emanate from many different agencies and under many congressional bills enacted over time, so the rules vary widely. However, since the original Hatch enactment, most of the federal support to agricultural research has traditionally been a direct grant under that act to the director of the

state agricultural experiment station for study of local problems. The amount of funds has been allocated to each station on the basis of the ratio of rural and urban population and has little relation to the importance of the state's agriculture. From 1946 to 1975 for the Illinois station, the proportion of the total station's expenditures furnished by Hatch funds averaged 17.7 percent. In 1978 expenditures from state appropriations were about $2\frac{1}{2}$ times the Hatch appropriation, which Congress requires must be, at least, matched dollar for dollar above the minimum of \$90,000 it provides.

A requirement common to all federal allocations, however, is that the agency must approve the nature of the research and often the procedures to be used in resolving the problem; an audit review and approval of all expenditures are always required.

Other federal support of university research is by grant or contract. With contract support, arrangements are more formal and binding on the work to be performed, often stipulated to the last detail. Most such government allocations for research at universities are awarded to individuals or teams of investigators on a project basis, and to the university employer of the scientists solely for the purpose of the approved project.

Proposals for research projects to be supported in whole or in part by Hatch or McIntire-Stennis funds (both federal funds) must, by Washington insistence imposed over time, go through a review process that includes review by peer groups within the department or research unit, approval by the head of the department or unit, submission to the director's office, additional review by that office, approval by the director, and finally review and approval by the state station research monitoring arm of the U.S. Department of Agriculture. The process is time-consuming but effective in centralized top-level bureaucratic control. It establishes a collaborative decision assuring that the research will meet a common need and will use techniques recognized by other scientists. However, the process means that the scope and duration of the research are likely to be reduced below the researcher's request, that new ideas or approaches are likely to be squeezed out, and that the research won't be as much fun to do. It is the perfect formula for the bureaucratic "dead hand on discovery" described by Darlington (7) and an entrapment only the most adroit of state station directors can avoid. It is easiest to resist when state and gift funds clearly outweigh federal funds!

An important useful service provided the state stations is the USDA's system of on-site review of departmental or subject matter research progress. Earlier this was done annually by the USDA's Office of Experiment Stations, more recently by the Cooperative State Re-

search Service on a four-year schedule, and since 1976 by the USDA's Science and Education Administration-Cooperative Research (USDA-SEA-CR). Under the present agency specifications, a team of subject matter research specialists led by an employee of the federal agency but made up otherwise of peers in the subject matter examines in detail the research in progress. Before leaving the site after three or four days of examination, the team reports to the department or subject matter group and the station administrator its views of strengths and weaknesses of the program of research and its effectiveness. Later it files with the station and the USDA a written report of its findings. Such review teams are meticulous in avoiding ranking of stations as we attempt to do here.

Scientific Publications as a Measure of Research Productivity

In considering the number of articles published by an institution to be an index of its relative productivity, one must assume that the mill-run average of scientific and practical significance of the papers published is about the same for each institution studied. One can question the validity of such an assumption. Still, that is more likely to be the situation for scientific manuscripts subjected to review by editorial committees of peers before acceptance than it is for manuscripts not so reviewed. The review process places a floor for the level of merit for that particular journal.

There obviously are real differences in the scientific excellence or ultimate practical significance of the large numbers of papers published in the various subject matters of science pertaining to agriculture. The problem is that there is no practical way to make objective evaluations now or to assign acceptable numbers to any value judgments that are made. Attempts have been made to assess economic returns on investment in a broad program of research on a single commodity (3, 4, 9, 10, 16, 21, 22, 29), but to assess the contribution of an individual paper requires a time lag of years, by which time the value of the assessment as an aid in deciding about investment in particular research will have passed.

Because of the large number of publications included in this study, it is reasonable to assume for any station or research unit that exceptional research reports are balanced by mediocre ones, that the peaks and valleys level out. Although far from perfect, the system of counting publications has been probably the only practical way for the Illinois station to make comparisons. It is true that some institutions may be

more strict than others in what they will consider and report as a scientific publication; this fact may result in some aberrations, but we do not think it skews the data appreciably.

Source of National Data on Publications Output

The major source of data from the states was the annual summaries prepared by the USDA Office of Experiment Stations for 1945-1959 and by the USDA Cooperative State Research Service for 1960-1975 (1, 2). Each station reported annually its technical journal articles, bulletins, circulars, and similar output of the station. Only the number of technical journal articles published was used in our study as evidence of scientific productivity. There were some blanks in the data when a station failed to file a report with the USDA (as Illinois failed to do in some years before 1950 because of a dispute between Illinois and the USDA).

National average salary levels, staff numbers, funding, and total funding sources were also part of the OES and CSRS reports. Those data did not deal with individual subject matter fields and did not attempt to compare and rank the stations accordingly.

Study I: A Review of Station Publication Numbers Reported by OES and CSRS

This review of experiment station productivity began with an analysis of the OES and CSRS annual reports from 1945 through 1975.¹ The annual number of technical journal articles was compared with the number of scientific workers at each station and with the federal and state dollars allocated annually for research at the stations.

Total investment in research at the state agricultural experiment stations was 18 to 20 times as much in 1975 as in 1945, but the purchasing power of the dollars declined steadily during the period (Fig. 1). In terms of constant value dollars (15), the investment by the federal government and the state increased about 7½ times in the period. Funding per scientist increased and the number of scientists more than doubled. Publications by all stations increased throughout the period in a fairly consistent relationship to constant-value dollar inputs.

¹ In the OES and CSRS reports, years are fiscal years; fiscal year 1946, for example, ran from July 1, 1945 through June 30, 1946. In 1977 the new title for the USDA agency for relations with the state agricultural experiment stations became Science and Education Administration-Cooperative Research (SEA-CR). It discontinued reports of total funding and publication output of each state station with the 1975 fiscal year.

Figure 1. Indexes of changes in funds, staff, and publication output for U.S. agricultural experiment stations, 1945-1975.

Figure 2. Indexes of changes in funds, staff, and publication output for the Illinois Agricultural Experiment Station, 1945-1975.

The pattern for the Illinois station is similar to that for all stations except for the lesser increase in state dollars near the end of the period (Fig. 2). When Illinois is compared with all state stations, it is seen that Illinois received proportionately less total money and operated with relatively fewer scientific staff, but produced relatively more technical articles (Fig. 3). Illinois is consistently the nation's third or fourth producer of agricultural commodities, measured by dollar value, yet it puts relatively less into its agricultural research system than does the nation as a whole.

We next considered the position of the Illinois station in the top ten stations in total technical journal publications in the three decades from 1946 to 1975 (Table 1).

In the first decade, 1946-1955, Illinois did not report to OES for the first three years of the period. Although it ranked ninth on the basis of the total reported for the decade, it ranked fourth on an average annual basis for the reporting years. In the second decade it ranked

Figure 3. Rates of growth in funds, staff, and publication output for the Illinois station and for all state agricultural experiment stations from 1945 to 1975.

fourth, and in the most recent decade it ranked sixth. In each decade the top ten stations in technical publication output produced more than half of the total publication output for all stations. Twelve states in the North Central Region — Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin — produced 30 percent of the national output of state publications.

Concerned as we were at the time with the relative position of the Illinois station in productivity and with its financial support as compared with that of other states, the data were initially compiled for states as a unit. Thus we lost the distinction for Connecticut between its agricultural experiment stations at New Haven (the first in the United States)

Table 1. Number of Technical Journal Articles by the 10 Leading Agricultural Experiment Stations Reported to the USDA Office of Experiment Stations and the Cooperative State Research Service, 1946-1975

1946-1955		1956-1965	
1 New York	5,900	1 California	11,745
2 California	5,677	2 New York	5,376
3 Wisconsin	2,689	3 Wisconsin	3,369
4 Texas	1,243	4 ILLINOIS	3,036
5 Florida	1,230	5 Texas	2,908
6 Minnesota	1,226	6 Iowa	1,994
7 Kansas	1,212	7 Minnesota	1,741
8 Iowa	1,140	8 Indiana	1,568
9 ILLINOIS*	1,045	9 Michigan	1,566
10 Washington	996	10 Virginia	1,507
Top ten total	22,358		34,810
Percent of all stations	63.9		58.8
Total for all stations	34,971		59,211
1966-1975		Total 1946-1975	
1 California	15,254	1 California	32,676
2 New York	6,968	2 New York	18,244
3 Texas	6,874	3 Wisconsin	12,375
4 Wisconsin	6,317	4 Texas	11,025
5 Oregon	4,338	5 ILLINOIS*	8,394
6 ILLINOIS	4,313	6 Minnesota	6,417
7 Georgia	4,035	7 Iowa	5,896
8 Kansas	3,518	8 Oregon	5,790
9 Minnesota	3,450	9 Michigan	5,770
10 Michigan	3,328	10 Kansas	5,497
Top ten total	58,395		112,084
Percent of all stations	52.7		54.7
Total for all stations	110,807		204,989

* Total for three years not reported.

and at Storrs, and for New York the distinction between its two stations, one at Geneva and the larger one at Cornell University, Ithaca. The three California locations, Berkeley, Davis, and Riverside, were administered as one unit, and were so reported to OES and CSRS. In the discussion which follows detailing state or federal funding for state agricultural experiment stations and mentioning rank order, the reader should recognize this colligation for those states.

Annual OES and CSRS reports show wide divergence among the states in the dollars expended and the number of scientist years devoted annually to agricultural research. Such differences suggested that at least a part of the reason for the rank order position of a state's station or stations was explained by differences in those two primary inputs.

Wondering whether stations differed in total publication output for reasons not reflected by the number of state or federal dollars invested and the number of scientists dedicated to the research, we studied the publication record of all stations for a single year, 1975, in relation to their funding and staff size.

By appropriate statistical techniques, the influence of one or another of these measured inputs could be treated as a constant for all stations and the effect of the remaining variables studied. The effect of such data treatments on the total publication output of the ten leading publishers for the one year, 1975, is shown in Table 2. Though the California station employed the largest scientific staff that year, statistical adjustment for that part did not change the relative position of the California station as the producer of the largest number of technical

Table 2. The 10 Leading State Agricultural Experiment Stations for 1975, Based on Technical Journal Articles Reported to USDA Cooperative State Research Service

	Number of technical journal articles	Adjusted for		
		Staff size	Federal dollars	State dollars
1 California	1,720	California	California	Wisconsin
2 Wisconsin	1,023	Wisconsin	Wisconsin	Tennessee
3 New York	911	New York	New York	California
4 Texas	731	Tennessee	Oregon	New York
5 Tennessee	625	Texas	Kansas	ILLINOIS
6 ILLINOIS	601	ILLINOIS	Minnesota	Oregon
7 Georgia	513	Georgia	Michigan	Michigan
8 Oregon	499	Michigan	Nebraska	Indiana
9 Indiana	481	Minnesota	ILLINOIS	Texas
10 Michigan	471	Indiana	Tennessee	Utah
Total all stations	13,526	...	...	...

publications from its research. So too statistical adjustment for constant federal dollar inputs that year to all stations did not shift the relative California publication output. However, when the differences in state dollar inputs were statistically controlled, the adjusted position of California was downward, indicating that that state in 1975 put more state dollars into each of its publications than did those above it in the adjusted rank array.

Tennessee ranked high in publication output for that year and appears for the first time in the tables as a result of an uncommonly high single-year reported output. The figure reported by CSRS was 625 for 1975, but the average was only 124 for the nine prior years of the 1966-1975 decade. The Illinois position for the single year was not changed much from its relative position for the decade. The shift downward in its relative position by holding the federal dollars as a constant for all stations indicates that Illinois was more dependent on the federal source of funding for its relative position than most states. This reflects the relatively poor funding that the state provides in support of its agricultural research.

Wisconsin which had ranked third and fourth in technical journal publications in the three decades (Table 1) was shown for the year 1975 to be first when adjustments were made for state dollar inputs (Table 2). Later findings show that Wisconsin used its state dollars effectively in other years; possible reasons for this effectiveness are discussed later, beginning on page 28.

Study II: Peer-Edited Journal Articles

When summations of CSRS-reported station publication output in the decade of the 1960's were first used by the author, they had low credibility within the University of Illinois as indicative of how effectively the scientists and departments within the Illinois Agricultural Experiment Station were performing their responsibilities in agricultural research. At the same time the university publicists were placing great credence on the periodic opinion surveys of the American Council on Education, especially when a department involved in the survey was ranked high nationally by peer opinion. Agricultural subject matters were never considered by these trend-setting reports of the American Council on Education.¹ It seemed there ought to be a more objective way than peer opinion of measuring merit and effectiveness of research, if not teaching, units.

¹ Not until the Ladd-Lipset survey of 1979 (*The Chronicle of Higher Education*, January 15, 1979) did agriculture as a college receive attention (25).

Study IIa: Journal Articles — Animal Agriculture, 1958-1960

In 1961 the author, with graduate student assistance and support of his departmental colleagues, conducted studies on the research output in five scientific journals dealing with domestic animals: *American Journal of Veterinary Research*, *Journal of Animal Science*, *Journal of Dairy Science*, *Poultry Science*, and *Veterinary Medicine* (since changed to *Small Animal Clinician*). Full-length articles, technical communications, and abstracts of research reports were all counted and credited to the institution or organization employing the author or authors. A paper coauthored by scientists from different research institutions was credited to each employer at a rate proportional to the number of authors employed by that institution, regardless of the order of authors.

The summary for 4,119 titles published in the five journals during the three years 1958, 1959, and 1960 showed that the USDA as the employer of the publishing scientist ranked first with 336 papers. The next nine were the state agricultural experiment stations of Michigan (238), Illinois (236), Wisconsin (221), New York, Cornell (194), Iowa (185), Ohio (184), California (176), Texas (161), and Washington (144).

Study IIb: Journal Articles and Opinion Survey — Animal Agriculture, 1965-1967

A second journal survey of the research productivity in the field of the larger domestic animals was initiated in 1968. Poultry research was not included as it was thought then to be too heavily concentrated in only a few states (see for example Reference 5). Thus the journal *Poultry Science* was not reviewed as to the source of its published articles. The period selected for study was 1965, 1966, and 1967. All communications for the period were counted and credit allocated to employers as earlier described. Confining our interest to the USDA and the state agricultural experiment stations, we ranked them in order by the number of articles published by their scientists.

Simultaneously we planned a study to compare the research publication output by states in the four journals for the 1965-1967 period, with the opinion of a substantial number of colleagues as to their ranking of the stations as scientific and teaching centers.

A panel of 104 animal scientists and veterinarians was selected on the basis of their distinguished research on large animals. At the time of the survey, ten of the 104 were directly employed by the USDA. Wisconsin employed six of the panelists, and fewer numbers were at any of the other agricultural experiment stations. Seventeen of those

Table 3. Numbers of Technical Journal Articles Reported by the 12 Leading State Agricultural Experiment Stations to the USDA Cooperative State Research Service as Having Been Published in Fiscal Years 1967, 1968, and 1969^a

	1967	1968	1969	Total
California	1,640	1,679	1,461	4,780
New York	529	709	664	1,902
Wisconsin	272	625	...	897
Texas	430	1,372	539	2,341
ILLINOIS	433	345	443	1,221
Minnesota	300	329	352	981
Iowa	259	224	253	736
Oregon	281	364	416	1,061
Michigan	247	430	145	822
Kansas	191	308	359	858
North Carolina	215	234	254	703
Indiana	250	257	330	837
Total all stations	9,021	10,751	9,445	29,217

^a The time span for the three fiscal years, July 1, 1966-June 30, 1969, begins six months earlier and ends six months earlier than the 1967-1969, three-year calendar-year span of the peer-edited journal study.

selected were veterinarians; practically all of the nonveterinarians had earned the Ph.D. Biographical data from *American Men of Science*, available on about three-fourths of the members of the panel, showed that average age was 50 years. Cornell was most frequently cited as the institution where panel members had earned their doctorates, followed in order by Wisconsin, Missouri, Illinois, and Michigan State.¹

In the belief that respondents would be less inclined to evaluate or rank institutions from a list of 50 entities, five sublists of ten institutions were constructed. Every fifth institution on the master list, which was a ranking according to publications output, was placed on one of the sublists. For example, sublist 3 was composed of the 3rd, 8th, 13th, ..., and 48th institutions from the master list. Institutions were then arranged in alphabetical order within the sublists. One deviation from this pattern was that the Oregon and Virginia stations, with identical numbers of publications, were placed in the same sublist.

Each panel member received the five sublists but was not informed of publications output or on what basis institutions were assigned to the lists. Respondents were asked, in an accompanying letter, to:

... make a value judgment and rank the institutions in numerical order one through ten (one being the highest order of excellence and ten being the lowest within any one list) based on your idea

¹ Stations at New Haven, Connecticut, and Geneva, New York, as well as those in Alaska and Puerto Rico were not included in this analysis.

of their productivity. Productivity should be assessed in terms of quantity and quality of research published, its originality, and the quality of graduate student produced as estimated from your experience.

In the special case of the USDA, respondents were asked to:

... consider primarily the quantity, quality, and originality of its published research in your field.

Of the 104 selected panelists, 85 (82 percent) returned their survey materials as requested. Names of the panelists were not associated with their ranking of institutions; survey materials were entirely anonymous when returned by respondents. Results are summarized in Table 4.

The dominance of a few institutions in research in the large-animal field is obvious. The list of leading institutions is similar to that found for the 1958-1960 period, though that survey included poultry science.

The magnitude of intraclass correlation coefficients (r_i) can be taken as a measure of the *uniformity* of opinions in the ranking of institutions within sublists. Coefficients significantly larger than 0.5 indicate that variability of rankings was greater among the ten institutions than among the 85¹ opinions within each institution. Four out of five coefficients were larger than 0.5, but only two significantly so ($p < .05$). The lowest intraclass correlation was recorded in sublist 4 which included both Oregon and Virginia, suggesting that institutions with equal publications within a sublist presented a more difficult ranking task for panelists.

Standard deviations of rankings indicate the variability of opinions as to the ranking of individual institutions. Opinions varied widely for several institutions, notably the USDA and Georgia, but a relatively firm consensus was reached in the ranking of Cornell, Ohio, Iowa, Purdue, and Wisconsin within respective sublists. Although respondents were asked to rank institutions on *qualitative* grounds as well as quantitative output of research publications, difference in quantity of publications is shown to account for about 69 percent of the variability in subjective rankings. When the USDA was omitted, publications output accounted for 94 percent of variability in rankings of the state agricultural experiment stations. These data could be interpreted to mean (a) that respondents were highly influenced in the ranking task by their perception of the quantity of research output of institutions, or (b) that respondents did accurately gage the quality factor and that quantity and quality in research do in fact go hand in hand.

Two institutions were noticeably underranked in relation to their

¹One respondent declined to rank institutions in sublist 3, leaving 84 opinions for that sublist.

Table 4. Publications Output and Peer Ranking Data of Institutions

Institution	Number of publications 1965-1967	Opinion mean rank	Opinion standard deviation	Modal rank
Sublist 1 — $r_1 = 0.66$				
USDA	368	3.36	3.21	1
Michigan	175	1.88	1.09	1
Minnesota	115	3.38	1.57	3
Pennsylvania	85	3.84	1.86	3
Oklahoma	71	4.39	2.09	4
Maryland	50	5.81	1.49	6
Arkansas	35	7.68	1.90	8
Alabama	26	7.85	1.52	8
Massachusetts	16	7.61	2.34	9
Vermont	8	9.00	1.29	10
Sublist 2 — $r_1 = 0.70$				
Wisconsin	204	1.54	.93	1
California	171	1.93	1.08	2
Georgia	96	5.90	3.64	5
Kentucky	84	3.98	1.85	3
Tennessee	60	4.80	1.55	4
Connecticut	47	6.40	1.89	8
Utah	34	6.15	2.17	5,6,7
Clemson (South Carolina)	23	7.18	2.00	8
Maine	14	8.50	1.52	9
Delaware	5	9.00	1.60	10
Sublist 3 — $r_1 = 0.76^a$				
ILLINOIS	202	1.93	1.41	1
Iowa	162	1.60	.86	1
Nebraska	92	4.38	1.92	4
North Carolina	82	3.68	1.91	3
Colorado	58	4.76	1.48	4,5
Louisiana	47	6.31	1.81	6
South Dakota	29	7.04	1.68	7
Montana	23	8.23	1.36	9
New Mexico	13	8.62	1.30	9
New Hampshire	3	8.39	2.27	10
Sublist 4 — $r_1 = 0.45$				
Cornell (New York)	189	1.12	.46	1
Ohio	156	2.14	.72	2
Oregon	80	4.67	1.75	4
Virginia	80	4.79	2.50	5
Washington	54	4.68	1.62	3
Rutgers (New Jersey)	43	5.19	2.31	4
West Virginia	28	6.93	1.54	7
Nevada	22	8.79	1.44	10
Mississippi	12	9.27	1.52	10
North Dakota	2	7.99	2.52	9
Sublist 5 — $r_1 = 0.76^a$				
Purdue (Indiana)	176	1.50	.93	1
Missouri	122	3.02	1.85	3
Kansas	85	3.74	2.07	4
Texas	76	3.62	1.57	5
Florida	54	4.44	1.81	5
Arizona	42	5.92	1.61	6
Wyoming	27	7.29	1.44	7
Hawaii	18	9.01	1.51	10
Idaho	11	7.42	2.18	7
Rhode Island	1	8.89	1.54	10

^a Correlation is significantly ($p < .05$) different from 0.50.

output of publications. It cannot be discerned from these data whether the USDA and Georgia were undervalued for reasons of quality because of a time lag in recognition of prominence or because of other confounding factors. It has already been noted that variability of opinions concerning these institutions was greater than for any others. Also included in Table 4 is the modal, or most frequently given, ranking of each institution.

Study IIc: Full-Length Journal Articles — Ten Agricultural Subject Matters, 1967-1969

The two analyses of research productivity of the animal agriculture research units of the USDA and the state agricultural experiment stations suggested that the technique was at least as useful for our purposes as an opinion survey. CSRS reports on publication output by stations did not provide the evidence on departmental competence required by the University of Illinois when in the late 1960's it began its period of extensive self-examination under the faculty Council on Program Evaluation. Therefore a project was initiated in 1971 to expand the study of peer-edited journal publications to all subject matters in agriculture represented by the ten Illinois departments and two research units in the station.

The study included 55 sources of publication output (50 of which were the agricultural experiment stations of the 50 states); ten subject matter areas (based on departments and units in the Illinois station, except that Animal Science, Dairy Science, and Veterinary Research were combined); and three years (1967, 1968, and 1969). Analyses were made of 66 peer-edited journals (see Appendix), 31,911 full-length articles, and roughly 75,000 authors. Credit for multiple-author publications was assayed by an equal share to each employer, regardless of the order of authors. Analysis showed that the distribution of these observed data (x) was normalized by the transformation $\sqrt{x + 0.5}$.

Experiment station authors published 34.2 percent of the articles included in the study, and others in non-experiment station departments from the same land-grant university contributed 6.3 percent; 40.5 percent of the articles therefore came from land-grant universities. The rest of the articles were divided as follows:

Non-land-grant colleges and universities	13.2 percent
U.S. Department of Agriculture	12.3 percent
Federal other than USDA	4.8 percent
Private research institutes	6.1 percent
Foreign country nationals	23.1 percent

Year-to-year variability of output was slight among the 50 states and the ten subject-matter areas, with intraclass correlations of 0.97 and 0.98 respectively. Thus nearly as precise an estimate was made of the relative position of the stations of the 50 states for output of peer-edited publications during one year as was found for the three years.

When the output was analyzed for total peer-edited publications, publications per full-time staff, and average cost per publication and the top ten ranked by each of these criteria or by them combined, many of the same leaders revealed in the CSRS study again came to the fore.

The peer-edited publication analysis also permitted verification of the validity of using CSRS reports to measure individual station publication output from 1967 to 1969; 35.9 percent of the publications reported to CSRS were accounted for in the 66 peer-edited journals reviewed, and for Illinois 40.5 percent were accounted for in those journals. Correlation between rank orders of the stations derived from each study for the three-year period was high (0.9198), indicating that the two systems were similar. The variance of one method explains about 85 percent of the variance of the other. (See Tables 3 and 6 for the rankings of the top stations under either analysis for the comparable time period.)

Evidence clearly indicates that the agricultural experiment stations of the 50 states vary significantly in scientific output. Although it is often thought that there must be a minimum critical mass for optimum scientific output, in the peer-edited journals reviewed the relationship between station staff numbers and output is not high, explaining less than 25 percent of the variance of station output.

The federal dollars invested under the Hatch Act in state experiment station research, which vary little from state to state, bear no statistical relationship to a station's output of peer-edited publications though obviously paying for a lot of them. There is, however, a direct and significant relationship between total and state dollars and the station's publication output.

Illinois Rank by Subject Matter Areas — Peer-Edited Journals

Our study of peer-edited journals gave us an opportunity to compare the research productivity of Illinois departments and units with the publication output in the same subject matters at other stations. Since Illinois has fewer departments or research units than most stations, subject matter classifications at Illinois apply only approximately to departmental designations of other stations. For some stations several units had to be combined into one to correspond to the Illinois divisions.

For animal agriculture, for example, excluding its economics, use of two broad categories of subject matter, animal production (animal sciences) and animal protection (veterinary medicine) permitted sorting publications into recognized areas of research despite wide variations in department designations and organization at the state stations. For twelve stations the animal sciences publication output in the 66 journals was combined for three departments and for nine stations the output of two departments. No journal dealing specifically with veterinary medicine was included in the 66 journals surveyed. Still, 6.7 percent of the papers published by the Veterinary Research unit of the Illinois Agricultural Experiment Station in 1967-1969 were published in the 66 journals.

In these distributions of publications to subject matter categories at each station, some irreconcilable conflicts with the Illinois designations were found which were accumulated under an "other" classification. These included meteorology, biochemistry, molecular biology, botany, statistics, microbiology, viticulture, agricultural education, landscape architecture, basic genetics, conservation, environmental science, journalism, Experiment Station, and perhaps others; all of these papers were credited to the totals for each agricultural experiment station.

The results of the study by subject matters are shown in Table 5, including the Illinois contribution to the subject matter totals and the Illinois ranking by subject matters, which in all cases except that of the animal sciences and "other" are department or research unit designa-

Table 5. Number of Full-Length Peer-Edited Papers Published in 66 Journals, 1967-1969, by Subject Matters, Illinois Number, and Illinois Rank Among States

Subject	Total number	Illinois number	Illinois percent of total	National rank order
Agricultural economics	389.37	25.5	6.5	5
Agricultural engineering	607.10	28.78	4.7	4
Agricultural entomology	1,333.26	48.33	3.6	4
Agronomy	1,890.98	93.68	5.0	5
Animal sciences ^a	2,027.59	131.26	6.5	1
Food science	645.41	41.67	6.5	8
Forestry	400.23	14.00	3.5	7
Home economics	244.80	2.11	.9	29
Horticulture	572.68	46.57	8.1	4
Plant pathology	1,292.44	53.65	4.2	7
Other	1,511.32	9.9	<.1	^b
Total	10,915.18	446.85	4.1	6

^a Includes work in animal science, dairy science, and veterinary research.

^b Not applicable.

tions. The Illinois data reflect national patterns of publication output by subject matters for the 1967-1969 period. The Illinois station's contribution was 4.1 percent of the total by state agricultural experiment stations for the period. The broad categories of animal sciences and agronomy had the most publications. Referring to later tables, especially Table 10, one can see that that pattern of publication output for the several subject matters at Illinois persisted through 1978. It is likely that the pattern has persisted for the nation at large as well, but there is no evidence available to test the conjecture.

It is easy, of course, to count the publications and rank the states simply on the basis of the numbers. It is much more complicated to show whether the differences in rank are statistically significant. But once statistical procedures have been used, the apparent certainty implied by a ranking simply on the basis of number is erased. The use of statistical analysis also reduces arguments and disagreements.

The problem can be illustrated by the final analysis relating numbers of peer-edited publications to numbers of scientists and to total dollars invested (Table 6). For the mean annual output per subject matter unit by states for the three-year period, Illinois ranked sixth but could not be distinguished statistically as being significantly different from either the second-ranking state or the sixteenth with probability odds of 5 percent or less that any of the differences were not due to chance. When the output was adjusted for staff size and dollar investments, Illinois

Table 6. Rank Order of 10 Leading State Stations, by Least Square Means of Annual Publications per Subject Matter Unit and After Adjustment for Scientist Years and Total Dollars Invested, 1967-1969, in 66 Peer-Edited Publications

	Least square mean, annual publications per subject matter unit	Statistical signifi- cance ^a		Adjusted regression constants	Statistical significance ^a
1 California	35.13	A	Wisconsin	6.29	A
2 Wisconsin	19.67	B	Indiana	3.38	B
3 New York (2 stations)	16.21	BC	Michigan	2.62	BC
4 Indiana	13.13	BCD	Oregon	2.41	BCD
5 Michigan	12.59	BCD	ILLINOIS	2.38	BCD
6 ILLINOIS	12.53	BCDE	Connecticut (2 stations)	2.23	BCDE
7 North Carolina ..	10.95	CDEF	Massachusetts ...	2.18	BCDEF
8 Texas	10.16	CDEF	Iowa	1.53	CDEFG
9 Iowa	8.64	DEFG	Kansas	1.41	CDEFGH
10 Minnesota	8.56	DEFG	Colorado	1.29	CDEFGH

^a Stations followed by the same alphabetical characters are not significantly different at the 0.05 level of P.

was ranked fifth, but was not distinguishable statistically from states ranking second through eleventh.

Adjusting for scientist years and dollars invested resulted in some dramatic changes for some states. California was first in mean publications per subject matter area, but ranked 34th after the data were adjusted; New York changed from third to 31st; Texas from eighth to 44th; and Minnesota from 10th to 18th. The coefficient of determination, R^2 , for this latter analysis was 0.9807.

It should be noted that the Wisconsin station again topped the rank order listing when its output of peer-edited journal articles for the 1967-1969 period was statistically adjusted for staff size (scientist years) and dollar investments, just as it had in the CSRS data for the single year 1975.

The key to quality and the source of the inspiration to excellence are not revealed by the data recorded. The Illinois station staff has performed better than the product of its size and funding (see Fig. 3) and so have others. Wisconsin has excelled at the production of outstanding science at minimum dollar investment. Is it that the Wisconsin station has an "atmosphere" that is subtly more conducive to research and publication output which in the public national interest ought to be repeated elsewhere?

No concerted effort by the author has been made to explore the question of staff and dollar efficiency in publication output beyond observations at home and over the fence with neighbor Wisconsin. From the data made available from the historical records, from their statistical manipulation and analysis described herein, and from many communications with colleagues at Illinois, no consistent pattern arises throughout the administrative units, departments, and research units that explains the efficiency of the Illinois station. Clearly it has had overall a conscientious and loyal senior staff and its share of "stars."

The examination of the Wisconsin station has been much more superficial with far fewer conversations with station leaders and scientists. Only one consistent difference appears in the records from 15 deliberately scheduled conversations with colleagues at Wisconsin, most from the animal, dairy, food, and veterinary sciences. In those conversations one item came through, often as an afterthought to the question "If I were to show you that the agricultural experiment station at the University of Wisconsin is one of the most efficient producers of research information about agriculture, to what would you attribute that capacity?" Among scores of comments, eventually each person mentioned the Wisconsin Alumni Research Foundation funding to young faculty for approved research projects.

It is the writer's understanding that this annual allocation of substantial funding is awarded with high priority to beginning young faculty and is continued normally for three years, during and after which there is vigorous appraisal of progress and early performance. The scientist is encouraged early to seek outside funding for research, the WARF application and review serving as a useful training experience.

This policy was said to discourage appointment to tenure track by departments or research units of young aspirants whose earlier record might suggest them to be incapable of meeting minimum peer standards and accustoms the beginning scientist to the need for and procedures involved in assuring continued funding of a research career. It encourages and stimulates administrative surveillance of young staff performance. The review process for continued funding offers the appropriate occasion for inspirational aid and performance demands antedating the end of the customary six-year limit before permanent tenure decisions are made. This beginning assurance of modest funding for young faculty in agriculture to test research and scholarly capacities is considered by all with whom the subject has been debated at Illinois, Wisconsin, or elsewhere as being an opportunity to be envied and emulated.

Apart from revealing the specific stations with which Illinois was competitive in specific subject matters, these analyses of peer-edited publications for three years revealed little that had not been recognized for the longer-time trend by the analysis of OES and CSRS data for the states' stations as a whole during the 1946-1975 period (totals for Illinois and for all states are shown in Figure 3). The much more detailed analysis of the source of full-length peer-edited scientific papers in the agricultural journals has yielded much more precise evidence for comparative purposes, especially in the specifics of subject matter. It is, however, very laborious and time-consuming to survey journals page by page, allocating credit to the employers of authors; it is a relatively expensive technique, not for routine use. With the development of computer storage of library data and rapid retrieval, we hoped that the authors of papers appearing in an even larger sample of prestigious journals could be computerized as the technique of the future. However, it was found in one test of the system in 1978 that library retrieval-of-information services are not yet organized to record the employer of each author. Thus a new system will have to be developed to provide information on comparative station competence that was readily available from CSRS reports before the Science and Education Administration-Cooperative Research eliminated them in 1976.

There remained the question whether the selected journals adequately reflected the publication outputs of subject-matter departments of the

different states. There was no way to test the assertion of some that the 1967-1969 period was not characteristic of their department's long-term productivity without going to a great deal of additional time, expense, and data-gathering. Being interested primarily in comparing the Illinois subject matter units with units in other states legitimately similar, we sought data on the total publication output of departments in the ten top-ranking stations for 1967-1969. Such information might indicate the sampling adequacy of the 66 journals selected for our review. However, some of these ten stations did not publish a list of publications by their staff, and some who did publish them did not separate them by departments. Consequently we were not able to get the data needed to make comparisons between Illinois and other stations except for data arising from the study of the 66 peer-edited journals. The Illinois station has consistently reported by departments or research units, the research publications, the size of the scientific staff, and the dollar investments. The analysis in Study III deals solely with the Illinois station.

Study III. The Thirty-Year Research Productivity of the Illinois Station, Fiscal Years 1949-1978

The Illinois Agricultural Experiment Station reported annually on its stewardship of agricultural research at the University of Illinois until 1938. There was a long lapse in reporting before, during, and after World War II because of that emergency. A nine-year report of the Illinois Agricultural Experiment Station covering fiscal years 1939 through 1947 consolidated the cumulative record of the period. After a single-year report for fiscal year 1948 was published, its reports have been for two-year periods beginning with July 1, 1948, and ending on June 30 on each second succeeding year. Thus to date there have been 15 consecutive biennial reports of the station beginning with the initial one for 1948-50. The data for the following report are taken from that series.

Changes within the Illinois Agricultural Experiment Station from 1948 to 1978 were determined for each unit by compiling the number of professorial¹ staff members each year with some research appointment, the financial support, and the number of publications reported in the biennial reports of the station, and of those, the ones published as

¹ Includes assistant professors, associate professors, and professors. Beginning with fiscal year 1965, CSRS reports give "Research personnel full time equivalent," which is larger than our internal system of full-time-equivalent service; a review of our bienniums since that time indicates that had we adjusted head count to scientist years, the basic conclusions and areas of indecisiveness would not have changed.

full-length articles in peer-edited journals and in the 66 journals earlier sampled for Study IIc.

In examining the information carried in Tables 7, 8, 9, 10, and 11, it is essential to keep in mind that many variables beside staff size and dollars affect the publication of research. A major unmeasured variable is the scientific evolutionary development of a subject matter field. Rankings within the station are directly related to the types of research that the units traditionally conduct and the degree to which the units are involved in development, their size, and funding support.

Variations in the Nature of Agricultural Research

Agronomy (soils and crops at Illinois) and Horticulture traditionally do long-term research that carries with it much demonstration and developmental work, such as varietal development that falls just short of getting seed of a new variety, kind, or cultivar for multiplication, certification, and sale, all of which costs staff time but keeps the research relevant to the needs of practitioners.

The balance between research and development of Agricultural Engineering activities seems to follow the same pattern but for different reasons. Agricultural engineers must provide their own inertia for continuation of equipment development until industry can see its value and proceed to the final stages of adaptation and public availability; the problem is to keep an idea alive until industry picks it up.

In the departments of Animal Science and Dairy Science, on the other hand, tasks of demonstration and development are now left pretty largely to farmer cooperatives organized by the Cooperative Extension Service, to breeding associations, to industries servicing animal agriculture, and to farmers themselves. The scientist largely leaves exploitation of research findings to the Cooperative Extension Service and to industry. As between those two departments, the dollar investment in mature animals and their generation interval is greater for dairy cattle than for swine, sheep, and poultry.

The Department of Agricultural Economics, like other such departments, publishes much but relatively little in peer-edited journals. A basic reason for this is that agricultural economics as a field of study is not clearly independent from the study of economics as a whole. It is far less safely separable from the whole for assertions of principle than can be the assertion of principles of biology and their chemical and physical basis from studies on limited samples of plants or animals. Agricultural economics must deal with an audience that is more concerned with market fluctuations of individual commodities than with

analyses of factors controlling the fluctuation; the audience for the information largely has its own economic welfare at stake.

The Department of Food Science, created in 1947 from a core of milk technologists long a part of Dairy Husbandry (from which Dairy Science also emerged), has been evolving and seeking its place in the education process. In some respects the department was created as a response to Congress, which in revising the Hatch Act in 1946 consciously extended federal support for agricultural research beyond farm production and rural life to concern with marketing and consumer well-being. Successful research programs in the field range from the basics of human nutritional need and commodity chemistry to underwriting development of new food processing techniques. Publication standards and output should reflect this variation.

The traditional field of home economics, at Illinois known since 1974 as the School of Human Resources and Family Studies, sincerely concerned with teaching undergraduates, has not yet settled into a mature research and stable publication policy. The need is now widely recognized and changes may be expected. A basic question home economics faculties will have to resolve is the balance between the exploratory and the developmental research they ought to pursue. At some schools, as at Illinois, home economics suffered from being a sort of stepchild in the College of Agriculture.

Publication output in the Department of Forestry, as in all forestry work, has been tied to the long generation interval of trees and the relatively slow response of them to environmental change and experimental treatments. The one major exception has been in wood processing.

Plant Pathology, dealing with biological parasitism and its myriad manifestations, has a constant chorus of happenings to report. Turn-around time from experimental design to completion and publication is much shorter in this field than it is in most of forestry research and in the kindred field of animal disease research. In analysing publication output, higher weighting must be assigned to those papers that present the basics of control than for those that flag only the presence of a new opponent.

For two of the units, Agricultural Entomology and Veterinary Research, our data do not give a complete and fair picture. Agricultural Entomology is administered in the Illinois Natural History Survey and Veterinary Research in the College of Veterinary Medicine. While money from the Illinois Agricultural Experiment Station was used in some part of the work reported in each paper, the Illinois station did not pay all of the research costs.

Number of Staff

The number of professorial staff in the College of Agriculture holding appointments in the Illinois Agricultural Experiment Station increased steadily from 1948 through 1970, except for the 1962-64 biennium in which the numbers were the same as for the 1960-62 period. In the 1970-72 biennium period, state funds to the station were seriously slashed (by about \$500,000 annually), and the senior staff members decreased by the usual attrition. They increased a bit the following biennium but were again down in 1976-78 to the lowest figure since 1962-64. Simultaneously, the number of students in the College of Agriculture increased dramatically so that staff changes reflect in part an added commitment to the classroom.

In general, however, Agricultural Economics, Agronomy, and Animal Science all experienced major growth in total number of professorial staff members (assistant professors, associate professors, and full professors) involved in research. Lesser but fairly consistent growth occurred in Horticulture, Forestry, Food Science, and Agricultural Engineering. Dairy Science remained essentially unchanged throughout the period; Plant Pathology, Human Resources and Family Studies (formerly Home Economics), Agricultural Entomology, and Veterinary Research remained essentially static for the 20 years from 1958 to 1978.

The three departments with major staff growth at Illinois were also the major areas of growth nationally (17). The other research units also reflected national patterns of overall growth. The similarity in national and Illinois research subject matters and growth patterns suggests that the growths could have been the result of national plan, although the nation did not have a coordinated research planning system for the state agricultural experiment stations and the USDA until the early 1970's. The growth also might have resulted from other factors such as more aggressive leadership in the areas of major growth. It is more likely that it was a universal response to a felt need by the concerned independent decision makers.

Financial Support

The dollar figures in Table 7 are the total operation expenses for each unit for the biennium. They include salary for each scientist for the proportionate time on a station appointment; wages or salary for technicians, including post-doctoral appointments, graduate students, and hourly help; and clerical services. The figures also include expenses for equipment, livestock, occasional land rental, supplies, publication, and travel. The figures do not include costs of buildings and their heat,

power, and maintenance, or the original purchase price or rental of land that scientists use routinely.

The costs of doing agricultural research vary widely with the subject under investigation, animals being more expensive to maintain and have available than are trees, other perennials, and annual crops. Of all the departments or research units only Agricultural Economics, Food Science, and the School of Human Resources and Family Studies did not manage land. All others did in varying degree. Overall the operating expenses are about 80 percent for salary and wages of personnel.

Allocation of financial resources in an agricultural experiment station in principle is strikingly similar to the nutrition of human beings; before any productive outcome can be demanded at all, the system has to be kept alive, to be maintained. Only by allocations above that basic level of maintenance, which is different for the various subject matters and probably different for various states and regions, can one expect the resources allocated to research in a field to result in the output of an

Table 7. Illinois Agricultural Experiment Station Support to Departments and Research Units (in order of greatest to least)

1948-50		1958-60	
Agronomy	\$762,491	Agronomy	\$1,280,453
Animal Sci.	697,599	Animal Sci.	1,272,813
Hort. ^a	501,982	Dairy Sci.	785,050
Agr. Econ.	323,643	Hort.	776,553
Dairy Sci.	301,810	Agr. Econ.	690,024
Agr. Eng.	200,913	Food Sci.	632,739
Home Econ. ^b	135,193	Agr. Eng.	476,277
Food Sci.	112,497	Vet. Res.	309,595
Forestry	87,424	Plant Path.	277,791
Vet. Res.	81,727	Home Econ. ^b	266,295
Agr. Ent.	38,734	Forestry	203,867
...	...	Agr. Ent.	73,861
1968-70		1976-78	
Agronomy	\$3,174,407	Agronomy	\$4,606,320
Animal Sci.	2,412,852	Animal Sci.	2,748,991
Food Sci.	1,571,740	Agr. Econ.	2,332,342
Dairy Sci.	1,383,812	Food Sci.	2,265,459
Agr. Econ.	1,308,177	Dairy Sci.	1,949,270
Hort.	1,217,423	Hort.	1,885,976
Plant Path.	820,744	Agr. Eng.	1,323,995
Agr. Eng.	710,835	Plant Path.	1,126,439
Vet. Res.	621,554	Vet. Res.	872,147
Forestry	431,350	Forestry	788,240
Home Econ. ^b	361,984	Hum. Res. & Fam. Stud. ^b .	710,800
Agr. Ent.	158,074	Agr. Ent.	475,952

^a Plant Pathology combined with Horticulture for 1948-50 biennium.

^b The Department of Home Economics became the School of Human Resources and Family Studies in 1974.

intended product, in this case, needed, purposeful information. In the past and through the period covered by this study of research output, federal funding under the Hatch Act (and the McIntire-Stennis Act) could be allocated by the state station director to share a part of the inevitable maintenance costs. Under the competitive grants program initiated under the Food and Agriculture Act of 1977, that prerogative is denied the director and federal dollars may be used within the station only for the "above maintenance" function of designated scientists. In this manner at minimum costs and maximum control, the decisions about agricultural research for the future are more and more centralized in the Washington bureaucracy.

In general, the larger the research staff the greater the unit's total financial support. Agronomy and Animal Science gained the most in total support with increases in both staff and dollars during the 1949-1978 period. Next came Agricultural Economics, which had major growth in personnel, and Food Science, which increased both in staff and equipment.

Number of Publications

The numbers of publications by each department and research unit for 1948 through 1978 are given in Table 8. The total for the station was 12,546. In the period 1948 through 1976, the Illinois station published a total of 8,396 technical journal articles reported to CSRS, or 76.5 percent of the entire publication output of the station for the 1948-1976 period; the Illinois total for 1948-1976 was 11,405, of which 61.0 percent appeared in peer-edited journals and 54.2 percent were published in the 66 journals originally selected as the base of the 1967-1969 analysis. In selecting peer-edited journals, we were most successful with Agricultural Engineering and least successful with Veterinary Research, no attempt being made to include journals dealing solely with animal pathologies and their treatment or control. Of all Agricultural Engineering peer-edited publications, 82.4 percent were in the 66 peer-edited journals selected for our study, but for Veterinary Research the figure was 6.7 percent; Human Resources and Family Studies was the only other unit publishing less than half — 37.9 percent — in our 66-journal selection.

Publications per Scientist

In the earlier analyses of CSRS-reported technical articles published in 1975 by the state stations and in the analysis of the 1967-1969 pub-

Table 8. Scientific Publications, Professorial Staff, and Dollars Expended by Departments and Research Units of the Illinois Agricultural Experiment Station, 1948-1978

	Project years	Station publi- cations reported	Journal articles in peer-edited journals		Peer-edited articles in 66 journals, 1967-1969 study			Staff, head count, years	Total expended
			Number	Percent of total articles	Number	Percent of total articles	Percent of total head count, years		
Agricultural Economics	707	1,335	416	31.1	193	46.4	999	\$ 15,836,817.30	
Agricultural Engineering	341	475	284	59.8	235	82.7	484	8,794,496.63	
Agricultural Entomology	268	493	364	73.8	189	51.9	38	2,155,144.08	
Agromony	1,028	1,885	1,448	76.8	918	63.4	1,329	32,798,587.11	
Animal Science	618	2,066	1,256	60.8	778	61.9	752	26,578,936.51	
Dairy Science	313	1,296	609	47.0	352	57.8	516	16,199,148.50	
Food Science	395	754	663	87.9	311	46.9	489	15,993,863.16	
Forestry	284	488	185	37.9	102	55.1	303	5,290,816.06	
Human Resources and Family Studies ^a	179	237	113	47.7	45	39.8	270	4,677,465.54	
Horticulture	639	1,467	748	51.0	407	54.4	650	15,039,548.92	
Plant Pathology ^b	216	958	685	69.4	500	71.8	289	7,092,646.21	
Veterinary Research	361	1,090	804	73.8	53	6.6	449	6,318,013.20	
Total	5,348	12,546	7,575	60.2	4,083	53.9	6,566	\$156,775,483.28	

^a The Department of Home Economics became the School of Human Resources and Family Studies in 1974.^b Plant Pathology combined with Horticulture for 1948-50 biennium.

lications in 66 journals, we had for each station corollary data on the number of scientist years and the number of federal and state dollars invested in 1967, 1968, 1969, and 1975. The same kinds of analyses were contemplated for the Illinois output for the entire period 1948-1978.

On investigation, however, it was found that, while the percent of each scientist's appointment in the Agricultural Experiment Station was recorded in the archival budget books of the University of Illinois, no annual summaries of scientist years by departments were available earlier than for fiscal year 1965, as then stipulated by CSRS for its publication of annual data from the state stations. By recourse to the earlier annual budget books, the number of scientist years (full-time equivalent, or FTE under the University of Illinois system) back through 1948 could be laboriously dug from the records but that has not been done.

The writer has, however, compared the station records and the biennial report listing of staff head count for the seven bienniums 1964-1978, to find the relationship of professorial head count and FTE for the several departments and a school as follows:

	FTE is of head count (%)
Agricultural Economics	44.0
Agricultural Engineering	52.8
Agronomy	63.4
Animal Science	59.5
Dairy Science	68.3
Food Science	63.4
Forestry	52.5
Horticulture	63.2
Human Resources and Family Studies	31.9
Plant Pathology	74.7

The fractional full-time-equivalent appointments of the senior staff varied significantly from unit to unit but the relation one to another remained relatively consistent for the seven bienniums.

The bias involved in comparing publication output of the units on the basis of head count is obvious. Still head-count data for the first eight bienniums are all that are readily available. Use of these fractional coefficients for "correction" of the head count for all 15 bienniums provided no better precision in interpretation of the findings of the relationship of publication output to total funding from biennium to biennium than did head count. When calculated, however, on the basis of funding per scientist within departments for the last seven bienniums a consis-

Table 9. Publications per Senior Staff Year, by Head Count, and by FTE

	1948-1978, by head count		1964-1978			
	Station- reported articles per staff year	Peer- edited articles per staff year	By head count		By FTE	
			Station- reported articles per staff year	Peer- edited articles per staff year	Station- reported articles per staff year	Peer- edited articles per staff year
1 Agr. Econ. ...	1.36	.42	1.59	.56	3.52	1.23
2 Agr. Eng.	.99	.59	1.52	.92	2.81	1.70
3 Agr. Ent.	...	...	...	...	...	...
4 Agronomy ...	1.42	1.09	1.74	1.35	2.73	2.11
5 Animal Sci. ..	2.78	1.69	3.17	1.88	5.19	3.09
6 Dairy Sci.	2.52	1.18	2.82	1.27	4.01	1.84
7 Food Sci.	1.57	1.38	1.53	1.08	2.35	1.98
8 Forestry	1.61	.61	1.74	.71	3.37	1.35
9 Hum. Res. and Fam. Stud. ^a ..	.89	.43	1.03	.38	3.13	1.16
10 Hort.	2.27	1.16	3.05	1.64	5.76	2.56
11 Plant Path. ^b ..	3.62	2.58	4.61	3.35	6.06	4.11
12 Vet. Res.	2.47	1.82	2.86	2.05	...	...

^aThe Department of Home Economics became the School of Human Resources and Family Studies in 1974.

^b Plant Pathology combined with Horticulture for 1948-50 biennium.

tent pattern for most of them emerged. There was, of course, in some instances a decrease in the statistical significance of differences resulting from the decrease in degrees of freedom for the analysis (see Tables 10 and 11). Clearly for the long pull annual records of the FTE research appointments of the senior scientists of each department and research unit should be kept by the station office.

The means of departmental and research unit publications per scientist for 1948-1978 based on the head count and for the last seven bienniums based on both head count and the fractional FTE are shown in Table 9. It is the opinion of the writer that the true potential of any scientist in a field is far short of what might be suggested if the accomplishments of a part-time appointment for research are extrapolated to a full-time appointment. Research on difficult problems is an absorbing and preoccupying task. It is highly doubtful if there is twice as much time for thought, study, and speculation on a full-time appointment as occurs among the better scientists on a half-time research appointment.

Publications in Relation to Operating Investment in Research

We also considered the dollar investment for the 30 years in relation to total reported publications. During the 30 years, the Illinois staff published 12,546 papers and expended a total of \$156,775,483.40 (Table

9). Thus the average operating investment in every paper published was \$12,496 or \$20,696 if only peer-edited journal articles are counted, or \$38,397 if only articles in the 66 selected journals are counted. The data, however, should not be compared with present-day Illinois data. Because they are averages over a long period and because of the general inflationary trend for the period, they are far more characteristic of the early 1960's than of the end of the period.

The inflationary index for institutional costs of research and development was 196.56 for fiscal year 1978 as compared with 100 for fiscal year 1967. The lines of actual and constant-value dollars thus cross at a point early in the tenth biennium, not in the eighth which is the mid-point of this time series. A few more than half of the total publications had been reported by the end of the ninth biennium. For fiscal year 1979 the price index was 216.51, and for fiscal year 1980 it will be no less than 240. Prospects are that it will go even higher for fiscal year 1981 and later. Thus these cost figures must be doubled or more for estimates of necessary present investments.

The estimates for publication costs for Veterinary Research and for Agricultural Entomology were seriously biased to the low side because not all their costs were in the experiment station. Those two units are therefore omitted in some of the following comparisons.

The lowest average investment per paper was for the Department of Plant Pathology at \$7,404. The highest was in Food Science at \$21,212. There are logical reasons for such a variation.

Both departments were created at about the same time from parts of other existing departments. The Illinois Department of Plant Pathology was one of the official latecomers (1954) to a field long established and traditionally accepted as an area of investigation and teaching. The department was largely formed by bringing together small units that had been a part of other departments, and the plant pathologists were able to go right on with what they had been doing. Peers are not likely to pre-judge the significance of finding a new disease anywhere, and the outbreak of an old enemy in a new location under new environmental circumstances had equal significance. Thus rules of publication behavior in the field and standards have long been established in plant pathology. The standards are not any easier to meet than in other areas, but they are easier to recognize and to teach.

The emerging field of food technology, however, required larger investments in equipment for processing food, other than that derived from milk, and in other scientific and technical equipment necessary for research in human nutrition than Plant Pathology required for its work. As a newcomer to an expanding field where only a few departments had

been created earlier, the publications of scientists in the new department of Food Technology (now Food Science) faced higher hurdles for acceptance in peer-edited journals than became customary as the field rapidly developed to its present dimensions.

The number of dollars allocated to the departments and research units for four different bienniums is given in Table 7. Regardless of the trends evident in that table, station investment per publication though highest in the 1976-78 biennium increased relatively slowly, and showed no consistent pattern among departments. The output of station-reported publications increased at a rate of 76 publications per biennium over the 30-year period. There is highly significant statistical evidence, however, of a declining rate of increase in publication output over the last decade.

To maintain the 30-year trajectory of increased station publication output would require the addition of 1.37 staff members and \$46,040 to an average department for each additional paper published. But of course there is no average department; each is unique. Differences are due to inherent differences among the persons making up the contingent, to their different backgrounds and motivations, to the uniqueness of subject matter and the nature and degree of responsibilities they assume or have been assigned in the practical world, to the expectations and degree of support of their public clientele apart from students, to the financial and other facility support provided by their home institutions, and to the creative, zestful, and mutually supportive atmosphere of their institutions.

Corollary Changes Within Science as an Enterprise

Many others, too numerous to cite in a publication of this nature, have been concerned with the recent history of the expansion of science as a full-blown enterprise of modern man — as an industry of today's culture for assuring human progress. Most of the resulting papers and discussion have dealt with physics and the basic understanding of that field and chemistry. There have been few publications about the applied fields, especially agriculture.

The most detailed citations and valuable contributions are to be found in a book by Nicholas Rescher (19) of the University of Pittsburgh. Published in 1978, it is a philosophical essay on the economics of research in natural science. It is a thought-provoking discussion of science, its acceleration in its rate of growth and productivity of the recent past, and the seemingly inevitable deceleration which will result from the fact that the problems faced are more difficult and expensive of inputs

to resolve. Dr. Rescher details for basic science the facts of its relatively recent exponential growth and productivity. He describes how that explosive growth is being dampened by the increasing complexity of basic problems, and the difficulty of marshaling the total resources necessary for their resolution, including the maintenance of the quality of those inputs, so that scientists are likely approaching an asymptote in the rate at which discoveries will be made for understanding the complexities of natural phenomena. He presents views and theories advanced by some of the great leaders of science about these issues and about whether the principles to be learned from the scientific method are limited or limitless; he believes they are limitless, but presents theory and evidence to suggest that the deceleration of accomplishments in basic science is at hand. Even though science will continue to make great contributions to understanding nature, leading to its control for the benefit of man, such progress will occur at a slower rate and at increased cost.

Parallels in the applied sciences are revealed in the studies reported here of research productivity in state agricultural experiment stations. Total funding for such research grew since the end of World War II through 1975 at a compound annual interest rate of 10.4 percent, though the contribution of the federal government was a bit lower, 9.7 percent. This exponential increase has resulted in a doubling of the actual dollars appropriated by the individual state and federal governments of apparent funding for agricultural research every seven years. Inflation and the consequent reduction in the power of each dollar to purchase the collective resources necessary for agricultural research have reduced that apparent recent growth in agricultural research to a much more modest average increment of not quite 5 percent per year, equivalent to a doubling of constant-value dollars each 15 years or more. Illinois has not done as well as the nation as a whole.

Still the actual cost of station operation for each paper published did not increase as fast as one might have expected. Science too has its own technology, and this suggests that throughout the period of study the application of that technology and its efficiencies introduced in agricultural research were counterbalancing the increased complexities and difficulties of the problems studied. For the natural scientists in the station, the applicable technologies include those enabling them to control environmental conditions surrounding their material, new instruments with several powers of increase in perception and measurement of natural phenomena, and new techniques and methods for processing and interpreting their data. Modern computers and even electronic calculators under this last category were, of course, of infinite value, especially to the station economists but to most others as well.

The improvements have enabled agricultural scientists to tackle the complexities of their subject matter in a manner heretofore impossible. They have been able to redesign and conduct experiments relating to questions long asked in their fields, to generate data involving deliberate control and measured interactions, and to analyze their findings to an understanding which was primarily only highly speculative but a few years earlier.

Agricultural scientists seek fundamental knowledge of how to bring the parts of a very complex system together to increase the effectiveness of provisioning people. This is, of course, the reason for the involvement of specialists from several basic intellectual fields in the basic interactions of the endeavor, those of the physical and biological systems of nature in the production of useful, healthful commodities with the energy, distribution, processing, economic, and political systems of the world.

Statistical Treatments of the Data

As we have accumulated these data over recent years, we have from time to time subjected them to detailed multivariant statistical analysis. The presumed independent variables tested as potential influences on publication output were the department or research unit, bienniums, staff size as head count and scientist years (FTE), and actual and constant-value dollars (adjusted by the Sonka-Padberg cost-of-doing-research index (26)) allocated to each department or research unit. The first analysis for the data accumulated over 13 bienniums indicated that the rate of publication output at the Illinois station was beginning to slow down, which suspicion was verified by the analysis of the data accumulated for the 14th and 15th bienniums.

These data have been subjected to many different probings, but they are in fact limited and not capable of much valid manipulation. It was early recognized that the information bits are not independent one from the other. Inflation did not occur randomly among the 15 bienniums but followed a consistent upward time trend; so too did changes in staff size, total funding, and publication output. The multicollinearities were studied by calculation of the Durbin-Watson *d* statistic and inappropriate regression models so revealed abandoned. This simplification raised the issue of homogeneity of variances of the data within departments and bienniums. Tests of heteroskedasticity, or heterogeneity, of variances revealed significant differences for Agronomy, Horticulture, Plant Pathology, and Veterinary Research. Corrections of these data

resulted in no departmental position change or judgments about the basic inputs necessary for publication output.

The analyses were conducted including and eliminating the two atypical research units of the station, Agricultural Entomology and Veterinary Research. When these two units were eliminated from the

Table 10. Rank Order of the Illinois Agricultural Experiment Station Departments and Research Units in Publication Output Tested by Various Statistical Adjustments and Their Significance^a — for Station-Listed Publications

Rank	Dept. or unit	Mean per biennium	15 bienniums (1948-1978)			
			Adjusted for staff head count and			
			Actual dollars, dept. or unit		Const. val. dollars, dept. or unit	
1	Animal Sci.	137.7 A	Agronomy	A	Agronomy	A
2	Agronomy	125.7 AB	Animal Sci.	AB	Animal Sci.	AB
3	Hort.	97.8 B	Agr. Econ.	AB	Agr. Econ.	ABC
4	Agr. Econ.	89.1 BC	Hort.	AB	Hort.	ABC
5	Dairy Sci.	86.4 BC	Dairy Sci.	AB	Dairy Sci.	BC
6	Plant Path. ^b	79.8 BC	Food Sci.	AB	Food Sci.	BC
7	Vet. Res.	72.7 C	Agr. Eng.	B	Agr. Eng.	BC
8	Food Sci.	50.3 D	Vet. Res.	B	Vet. Res.	BC
9	Agr. Ent.	32.9 E	Plant Path. ^a	B	Plant Path. ^a	BC
10	Forestry	32.5 E	Forestry	B	Forestry	BC
11	Agr. Eng.	31.7 E	Hum. Res. and		Hum. Res. and	
12	Hum. Res. and Fam. Stud. ^c	15.8 E	Fam. Stud.	B	Fam. Stud.	BC
			Agr. Ent.	B	Agr. Ent.	C

Rank	Dept. or unit	Mean per biennium	7 bienniums (1964-1978)			
			Adjusted for FTE and			
			Actual dollars, dept. or unit		Const. val. dollars, dept. or unit	
1	Agronomy	184.0 A	Agronomy	A	Agronomy	A
2	Animal Sci.	174.7 A	Agr. Econ.	AB	Animal Sci.	B
3	Hort.	144.0 B	Animal Sci.	AB	Agr. Econ.	B
4	Agr. Econ.	122.3 BC	Hort.	AB	Hort.	B
5	Plant Path. ^a	106.9 CD	Food Sci.	AB	Food Sci.	B
6	Dairy Sci.	100.3 CD	Dairy Sci.	B	Dairy Sci.	B
7	Vet. Res.	89.4 D	Plant Path.	B	Plant Path.	B
8	Food Sci.	61.6 E	Agr. Eng.	B	Agr. Eng.	B
9	Agr. Eng.	49.4 EF	Forestry	B	Forestry	B
10	Agr. Ent.	48.7 EF	Vet. Res.	B	Vet. Res.	B
11	Forestry	47.6 EF	Hum. Res. and		Hum. Res. and	
12	Hum. Res. and Fam. Stud.	22.0 F	Fam. Stud.	B	Fam. Stud.	B
			Agr. Ent.	B	Agr. Ent.	B

^a Departments or units followed by the same alphabetical characters are not significantly different at the 0.05 level of P.

^b 12 bienniums.

^c The Department of Home Economics became the School of Human Resources and Family Studies in 1974.

total station analysis, the colligated results for the station as a whole were more precise, the standard errors of coefficients were smaller, and the coefficients of determination (R^2) for the regression analysis were larger. However, those research units were an important part of the overall station research program, being all of the so-called large animal

Table 11. Rank Order of the Illinois Agricultural Experiment Station Departments and Research Units in Publication Output Tested by Various Statistical Adjustments and Their Significance* — for Peer-Edited Publications

Rank	Dept. or unit	Mean per biennium	15 bienniums (1948-1978)			
			Adjusted for staff head count and			
			Actual dollars, dept. or unit		Const. val. dollars, dept. or unit	
1	Agronomy	96.5 A	Agronomy	A	Agronomy	A
2	Animal Sci.	83.7 B	Agr. Econ.	AB	Animal Sci.	AB
3	Plant Path. ^b	57.1 C	Animal Sci.	AB	Agr. Econ.	ABC
4	Vet. Res.	53.6 C	Hort.	BC	Hort.	BCD
5	Hort.	48.9 CD	Dairy Sci.	BC	Dairy Sci.	BCD
6	Food Sci.	44.2 D	Food Sci.	BC	Food Sci.	BCD
7	Dairy Sci.	40.6 D	Agr. Eng.	BC	Agr. Eng.	BCD
8	Agr. Econ.	27.7 E	Vet. Res.	BC	Vet. Res.	CD
9	Agr. Ent.	24.3 EF	Plant Path.	BC	Plant Path.	CD
10	Agr. Eng.	18.9 EFG	Forestry	BC	Forestry	CD
11	Forestry	12.3 FG	Hum. Res. and		Hum. Res. and	
12	Hum. Res. and Fam. Stud. ^c	7.5 G	Fam. Stud.	BC	Fam. Stud.	CD
			Agr. Ent.	C	Agr. Ent.	D

Rank	Dept. or unit	Mean per biennium	7 bienniums (1964-1978)			
			Adjusted for FTE and			
			Actual dollars, dept. or unit		Const. val. dollars, dept. or unit	
1	Agronomy	142.6 A	Agronomy	A	Agronomy	A
2	Animal Sci.	104.0 B	Agr. Econ.	A	Animal Sci.	AB
3	Hort.	77.6 C	Hort.	A	Agr. Econ.	ABC
4	Plant Path.	75.6 C	Plant Path.	A	Hort.	BCD
5	Vet. Res.	64.3 CD	Dairy Sci.	A	Dairy Sci.	BCD
6	Food Sci.	51.7 DE	Agr. Eng.	A	Food Sci.	BCD
7	Dairy Sci.	45.0 EF	Food Sci.	A	Agr. Eng.	BCD
8	Agr. Econ.	42.9 EF	Forestry	A	Vet. Res.	CD
9	Agr. Ent.	37.1 EF	Animal Sci.	A	Plant Path.	CD
10	Agr. Eng.	29.6 FG	Vet. Res.	A	Forestry	CD
11	Forestry	19.3 GH	Hum. Res. and		Hum. Res. and	
12	Hum. Res. and Fam. Stud.	8.1 H	Fam. Stud.	A	Fam. Stud.	CD
			Agr. Ent.	A	Agr. Ent.	D

* Departments or units followed by the same alphabetical characters are not significantly different at the 0.05 level of P.

^b 12 bienniums.

^c The Department of Home Economics became the School of Human Resources and Family Studies in 1974.

protection area and a substantial segment of the plant protection work; so reality demanded their inclusion. In actual fact publication output was highly significantly different among bienniums, research units, dollars allocated, and number of professorial staff. The R^2 values for the multivariate regression equations for the station as a whole were about 0.84 when Agricultural Entomology and Veterinary Research data were included in the computations, and about 0.88 when they were not. Either analysis provided F values indicating that the probability of chance causing the overall differences shown was less than 1 in 1,000. Separate analyses revealed that the data for those two research units were atypical. For example, throughout the 30-year period a slower rate of increase in dollar investment by the Illinois Agricultural Experiment Station to Agricultural Entomology led to an apparent increase in publication output. Also, from the data available it appeared that the investment necessary to generate one paper in Agricultural Entomology was several times higher than in Veterinary Research. Neither of these potential hypotheses makes sense. The historical data from neither source reflect the actual inputs for the publication output.

The results for the two units are what one would expect from a situation in which the lesser contributor of major sources of financial support, with its funds widely distributed over most research of an organization, insisted on approval of and credit for all research in which any of its dollars were expended. It is clearly the result in this case of historical accounting and reporting procedures adopted by this station and this university when times were more gracious and the consequences of the procedures less potentially damning.

Time Trends in the Efficiency of the Illinois Station's Publication Output

Research publication output of the Illinois station responded to the increase in effective funding of equivalent-value constant dollars by an acceleration in numbers from 1948 through 1956.

At that point the rate of biennial increase in publication output per constant-value dollar of investment dropped in a decline persisting for six years. In the next biennium, 1962-64, the relative research output per dollar unit of investment began an ascent which terminated in its highest value in the 30 years during the 1974-76 biennium (see Fig. 4).

The reasons for the marked burst of output after World War II and then the sudden drop in the efficiency of publication output by the Illinois station senior scientists beginning with the 1956-58 biennium

are not apparent from the data on funding and staff size, nor is there other readily available, recorded evidence pertaining to the situation. As one on the scene at the time, however, it is the opinion of the author that the increase was due to the enthusiastic return to research by the senior scientists, the full professors, who, though on the job, had turned to other tasks and academic responsibilities during the war when the assistant and instructor ranks had been almost completely eliminated. That burst of output continued for a time by provision of apprentice help from aspiring returned veterans until retirements and other attrition concentrated in the mid-1950's reduced the number of senior experienced and competent professors. A period of time sometimes quite extended was required for the personnel hired immediately after the war to complete advanced degrees and to prepare themselves for serious research while engaged primarily at the time in teaching the large numbers of returning veterans seeking a university education. That drop in

Figure 4. Constant-value dollars, peer-edited scientific articles, and publications per million dollars for the Illinois Agricultural Experiment Station from 1948 to 1978.

research productivity, persisting for six years, was a belated cost of the war disruption.

The publication output reached a high asymptote for productivity for the 1968-1976 period for the combination of staff numbers, dollars invested, and facilities and "atmosphere" pertaining at the station. It decreased significantly in 1976-78.

The overall productivity of the Illinois station dropped in the final biennium of this time series from 1,573 to 1,186 total reported publications; a decrease of 387 and a decrease of 140 publications in peer-edited journals from the 1974-76 biennium. It appears that the system of research productivity was pretty well saturated during the 1970's and reached an equilibrium consistent with the value of its inputs. In the analysis of CSRS data for all the state stations, the slope of the annual overall productivity output line was as steep for the 1966-1975 decade as in the preceding two, indicating no general decrease up to then in research productivity. However, some of the more prominent and mature stations, and Illinois was among them, seemed to have reached a slow-down, as suggested by a decrease in the regression of technical journal publication numbers on years in the last decade of the 30-year period. The marked decline in the Illinois publication output was not apparent, however, until the 1976-78 biennium.

It would be of interest to know whether this abrupt cessation in the latter half of the 1970's of a long string of annual increases in research output was a national phenomenon or peculiar to the Illinois station. A pessimistic hypothesis is that the approach to an asymptote is a generalized phenomenon and that the decline in output after reaching a maximum may be, also. Our data here would suggest that this is inevitable unless substantial resources are continually added to agricultural research. If we are, however, to approach a level of zero growth in all science as others predict (see Rescher, 19), then there will be a slowing of technology inputs to the industry of agriculture and a decrease in the rate of its productivity growth, which has been twice as great as non-farm industry of this country (10).

Outlook for the Future Publication Productivity of Agricultural Scientists

Experienced scientists and research administrators all believe that there is more to the sum total of research output of a research organization than simply the number of scientist years and the financial resources invested in it. Reason, too, dictates that this is the case.

In examining this assumption, the fiscal history and production records of the Illinois station were more useful than the national evidence. The analysis showed that within that one station with its ten (or twelve) subject matter departments or units, its greatly varying investment over the years among those subject matters, and their differences in size and subject matter traditions, the most precise estimation of publication output for a subject matter was the multivariate relationship of the size of the professorial staff devoted to research (FTE) and the number of dollars invested per FTE in the subject matter field. However, such precise data were available only for the last seven bienniums of the Illinois analyses and not at all for other stations. Total dollar inputs are the product of the two. The relative predictive outcome for the two as independent variables and the single variable of their product as independent was estimated for the limited data of the seven Illinois bienniums for the ten (or twelve) subjects. Subtle differences found between the two analyses among departments did not change the departments' relative ranking to a significant degree; the correlation coefficient between the coefficients of determination for the two procedures was 0.9063. The single independent variable of total dollars available (as obtained from the OES and CSRS reports) as a time parallel in relation to the annual technical journal output of the station was then examined further.

Dependence of Publication Output on Dollar Investments

During the 30-year period 1945-1975, the annual total available funding of the state agricultural experiment stations in actual dollars as reported by OES and CSRS accounted for 68.4 percent ($r = 0.8273$) of the year-to-year variability in the stations' output of publications in technical journals. This amounted to an average investment over the period of \$26,431 per recorded publication of this kind. That figure, because the midpoint year for the publication numbers fell during 1966, would call for multiplication by 2.25 to 2.5 to equate with 1980 dollars.

For the Illinois station during a comparable time period, 1949-1978, the average funding available for each of its OES- and CSRS-recorded publications in technical journals was \$18,727 and it, too, would require multiplication by 2.25 to 2.50 to update to 1980. The year-to-year variation in the number of actual dollars available to the Illinois station as reported over the years by the OES and CSRS accounted for 76.3 percent ($r = 0.8737$) of the year-to-year variance in its number of publications in technical journals. Relating these latter figures to the actual annual expenditures as given in the 15 biennial reports of the Illinois

station for the period, at Illinois the mean cost per publication in technical journals was \$16,620 and the year-to-year variation in dollars expended accounted for 82.3 percent of the variance in station output of publications in technical journals.

As organized and administered during this time span, the availability of dollars clearly had a commanding influence on the productivity of the Illinois and other agricultural experiment stations. The Illinois station has been more efficient in the dollar cost of its OES- and CSRS-recorded technical journal output than have been the stations of the nation as a whole. Not only has the mean annual cost per publication been lower for the Illinois station than the average of the other stations, but the annual rate of cost increase per publication showed no statistically significant time trend for Illinois and a highly significant one for the nation as a whole of about \$650 per year.

Variations in Level of Investment in Agricultural Research

Viewed in the broadest sense, differences in dollar investments from state to state and within states to different problem areas of agricultural research are a reflection of how the public and its decision-makers view the importance to them personally of agricultural research. The public at large relates only superficially to the many different sequential human tasks in the food and fiber provisioning chain, and those in the majority in the population centers then relate if at all only to the farm production of the raw commodities they see in intercity travel and to food on the retail shelves. The colleges of agriculture early concentrated on agricultural production and only gradually have they expanded their own horizons, the degree to which they have been involved in research throughout the spectrum of provisioning people being dependent on the population density of the state.

Federal: Hatch and McIntire-Stennis

In the allocation of federal dollars to agricultural research, the federal Hatch and McIntire-Stennis funds are distributed for use by the states' stations by law on the basis of urban and rural population distribution within the states in relation to the national pattern and in such a fashion as to minimize differences in the federal allocation to the states. The top ten states in receipt of total federal funds in 1975 were Texas, North Carolina, Alabama, Mississippi, Georgia, Tennessee, Kentucky, Virginia, Arkansas, and Louisiana, the amounts varying from

\$6,428,023 to \$3,522,883. Each of these states has an 1890's land-grant college in operation. Illinois, with no 1890's college, ranked nineteenth with an allocation of \$2,679,199. This concentration of federal funding in the southern region bears little relation either to its agriculture or its agricultural research productivity and is justified on other grounds.

State

In the state funding of agricultural research, the relative allocations reflect state concerns. The ten leaders in 1975 were California, Florida, New York, Texas, North Carolina, Georgia, Minnesota, Mississippi, Wisconsin, and Ohio, with the levels of all nonfederal funding available for agricultural research varying from \$43,581,205 for the leader down to \$11,571,510 for the state in 10th position and to \$1,799,866 for the last state in order. Illinois ranked 18th with \$9,597,288.

No predominant and consistent pattern for the state and other nonfederal allocation to agricultural research in the states can be clearly demonstrated statistically though the effects of total population, levels of income from agricultural commodities, relative dependence on agriculture as an industry, and concern for consumer welfare can all be seen. Illinois, often ranking fourth and sometimes third among the states in income from agriculture, with a heavy population and a great industrial base, and Iowa, usually ranking third among the states in agricultural income but not having any great cities or a major industry base, ranked 18th and 16th respectively in the total state and other nonfederal funding available for agricultural research in 1975. It all apparently makes political sense but not very good survival logic.

Intrainstitutional Allocation of Funds

Within the land-grant university homes of the state agricultural experiment stations, resident teaching has carried a higher priority than research in the allocation of some resources. Throughout the entire period covered by these studies, this was most apparent in the hiring of professorial staff, although those with a research appointment were likely to have more discretionary dollars. Vacancies in subject matter teaching for the growing numbers of agricultural students were, rightly, filled first. The subject matter of research interest, but not necessarily the competence, of the new appointee was secondary.

Early in the 1945-1975 period, when the size of both the teaching and the research endeavor was smaller, specification of subject matters to be taught and professorial interest in doing so was probably of greater importance in staff selection than has been the case as the staff size has

increased. With the increase in size has come specialization and a continuing shift toward basic science orientation of the professorial staff. As the teaching load increased in recent years, tending to lower the proportion of the individual appointment to the research function, the number of individuals employed also increased and the number of basic disciplines and technical skills they represent expanded. The teaching load and the greater technical competence of the facilities provided have been the basic reasons why costs per publication, though increasing at Illinois some in the 30-year period, have not increased greatly. As numbers of college-age students decline during the next decade or so, research interests of new staff will play a greater role in their selection.

Still, with intrainstitutional hiring and promotion standards of the land-grant universities pretty much determined by interinstitutional trade and consultation (e.g., the requirement of letters of recommendation from peer-group leaders employed at sister institutions for promotion to tenured positions) and with the subject matters of research investment pretty largely determined in their objective thrust by the national planning and funding agencies and in their technical thrust by peer groups, one can believe that the rise in government support of all science, including agricultural science, since World War II has resulted in a commonality of institutional response attuned primarily to dollars. In the opinion of the writer, this trend, in the face of current inflation and public recognition of limitations to world resources for improvements in living standards and quality of life, is responsible for the present apathy, if not active resistance, of the public to the continual requests by scientists for increased funding for their specialty.

Public Examination Necessary

Public examination is necessary of the issues of funding of scientific research of all kinds and of domination by federal agencies of the directions of that research.

If, as many students of the problem seem to believe, the health of American science equates directly with the size of the nation's investment in it (12), then the present public questioning presages ill days ahead. Science to be applied in the interest of agriculture is likely to fare no better than and possibly much worse than that relating to other public issues. On the scale of national and individual survival, agriculture, even though it produces vital supplies of food and fiber, does not rank very high alongside public health, space, defense, and energy for investments in research, since this nation's productive capacity for some agricultural commodities exceeds our immediate internal demand.

Agricultural Research Necessary to National Welfare

Not yet have we, as a nation, fully recognized the tremendous economic and political role played by our national capacity to produce basic food and fiber in abundance. Not yet have we recognized that the United States cannot indefinitely maintain the present posture of the cornucopia or breadbasket of plenty for those less fortunate elsewhere unless we invest much more in learning what essential nutrients will ultimately require constant replenishment and how to do so effectively as they are withdrawn by soil manipulation, by erosion, and by long-continuing sale overseas of agricultural commodities from our unappreciated land resources.

So far in America's history, research resulting in decreases in necessary labor input to agriculture has accrued to the benefit of farm owners and operators while agricultural research increasing the amount of renewable necessary commodities produced has ultimately accrued to the benefit of the consumer (27). When in the future neither of these outcomes occurs and the struggle is to maintain production and labor efficiency at fixed sustainable levels, the societal benefits from agricultural research could be simply basic survival.

It is pessimistic and possibly unnecessarily modest for scientists of the field to view the health of agricultural science solely in terms of the level of public investment in it. The public and science in general have been apathetic about agricultural science (24) and some have viewed its isolation as self-imposed (14). Efforts to sustain its federal funding have come almost exclusively from within the body of science applied to agriculture and from the isolated industry itself. As the recent Nobel Laureate Professor Theodore W. Schultz and his students have so ably pointed out over the years, agricultural research has paid high returns as a public investment and high dividends in human survival and is basic to fulfillment of dreams of equitable world development (24).

Lessons From the Illinois Study

It would seem that in this rather detailed analysis of the scientific output of one state agricultural experiment station during a very brief historical time span in which all scientific publication output reached the highest level in world history, there are lessons to be learned.

1. The funding for the Illinois Agricultural Experiment Station in the 1948-1978 period very nearly achieved (the nation as a whole did reach that level) the status of an exponential growth curve; the coefficient of determination for the correlation between the log of the actual

dollar investments each biennium and the sequential number of the biennium being $R^2 = 0.9866$. The linear relationship between the actual dollars invested and the biennium number was nearly as high, however ($R^2 = 0.9773$), and not significantly different from the log relationship. There is no real likelihood of future indefinite continuation of this steep ascent.

The shape of that curve, however, was determined far more, it seems, by the irresistible trends of the American economy and the human population numbers since the end of World War II than it was by a deliberate, planned program for societal investment in science applied to agriculture. In general, past state and federal appropriations for agricultural research have pretty well paralleled one another, with the state appropriations increasing slightly faster. The Illinois station in relation to the agricultural productivity of the state has been poorly supported and thus, as pointed out earlier, more dependent for its relative agricultural science position among the states on federal funding than on state funding.

Much has been said in federal appropriation hearings during the past 30 years about support of agricultural science, but as has been well put by another "... there is about much that comes out of the government's writing apparatus, an air of unreality, in which words are used so as to mean as many things to as many people as possible" (11). Little was said in the Illinois legislature or in public debate about the health of Illinois's own agricultural science during the 30-year period until 1977 when in the face of an approaching decline in the state's population of school-age children, the state began planning for new long-term educational objectives.

2. The Illinois Agricultural Experiment Station already has experienced the inevitable funding decline in purchasing power, which has been paralleled by a decline in the rate of publication output and for one biennium at least in an actual decrease in publication numbers. One cannot be sure that the decrease in station output in 1976-78 from the high of 1974-76 logically can be attributed to parallelism of funding, and station output though given great credence in these studies cannot be depended upon as proof of cause and effect in one biennium. The slowly withering effect of the decrease in purchasing power of the dollars invested in agricultural research treats agricultural research no differently than it does all of American science and much of the American population.

3. In the author's opinion it is more than likely that the decrease in publication output we are witnessing is also the effect of the increasing basic difficulty in the problems tackled and of the passing of that great

and splendid body of dedicated scientists who elected to join agricultural academe after service in World War II.

4. In this 30-year period we have witnessed two peaks of research publication efficiency (peer-edited papers per unit of constant-value dollars) twenty years apart and not too different in height, which suggests that they may reflect one complete cycle in the human endeavor of an agricultural experiment station. The twenty-year span is a bit short for an average human generation interval, but when considered as the turnover interval for the veterans of World War II whose advanced degree studies were delayed so that they joined academe five to ten years later in life than the present newcomers, the parallel may fit.

If that in fact is the case, then we may expect a period of reduction in the efficiency of the Illinois station followed in time by a recoup of productivity. The nature and extent of that recoup and the speed of the recovery are tied to the quality and competence of the new people to be chosen as faculty replacements, their training, the nature of the problems they are called on to solve for agriculture, and the adequacy of the equipment and other facilities provided them for the resolution of those problems.

Publication Records as Indicative of Benefits From Research

In the present studies and analyses of several different sources of information about what agricultural scientists do with facts and information they acquire from the publicly funded research they perform for the public, the author has asked the reader and the paymaster, the public, to assume that numbers of publications equate with the ultimate down-the-road payoff in public benefits of agricultural research.

The author recognizes as he said some years ago, "If printed on cellulose-based paper these publications can be consumed with relish and physical benefit only by ruminants, and other organisms possessing distinctive enzymes for digestion of cellulose," none of which man possesses. Clearly, it is the theories, the concepts, the ideas, and prescriptions those papers proclaim which are of importance to the sustaining human society. Not all research returns a benefit. For that which does, the time span from discovery and publication to practical benefit is not immediate and the level of societal benefit varies widely.

This nation has benefited substantially from its investments in research at the state agricultural experiment stations, as has been shown in many studies, of which that of Evenson *et al.*, 1979, is the most

recent (10). So far we have not faced the issue or attempted to quantify in any way the quality of agricultural research. Because of the mandate for the research, the quality of its performance must relate in some tangible way to societal benefits. A human activity set in an environment (the land-grant universities) in which the rewards relate only incidentally to societal benefits arising from agriculture and more directly to the approval of colleagues in other fields bent on excellence in the basic sciences and the performing arts creates career hazards contributing to the isolation in academe of which agricultural faculties are accused. No one considering the issue has yet seemed to acknowledge that the expectations of the clientele (agriculture) and the expectations of the employer (the university) drum in different cadence even if both are presumed to be pointed in the same direction, human progress.

Agricultural scientists are faced with the ever-widening public awareness of the margin of hunger constantly tearing at the edges of the expanding world population and on occasion making great inroads by death from starvation and debilitation. They have been aware of this all of their careers (8). They have been waging a war against world starvation without much help (18).

The problem for those who make decisions about public investment in agricultural research (or any research for that matter) is that the decision for today's need had to be made yesterday; while that for tomorrow's emergency has to be made today. The studies reported here show that one objective way of estimating past performance and potential benefits from agricultural research is to measure the output of scientific publications over time. The technique is neither fool-proof nor time-tested. One cannot now predict with certainty individual and institutional response if public bodies were to institute such a device as an early monitor of returns from public investment in research. One suspects there might then be some effort by institutions to inflate evidence of research output. This would confuse the issue only to a limited degree, however, especially if all concerned participated in the finagle to the same relative degree.

In the study of relationships of the immediate past at the Illinois station, in which no conscious effort could have been made to manipulate evidence, no real and important changes over time could be observed in the relationship of station-reported to peer-edited journal publications among departments. Nor were there discerned any meaningful changes over time in the relationship of either of these to senior staff members, to investments of either actual or constant-value dollars, or to them combined. With the existing intrauniversity pressure for acceptance only of publications in prestigious peer-edited journals as evidence of schol-

arly and scientific attainment for promotion, it is surprising that such changes were not seen. To be sure, there were marked and continuing differences among the departments in the proportion of their total station-reported publications that appeared as peer-edited publications. This relationship was consistent over time and appeared to be more a reflection of the traditions of the field than of the internal university policy of conformity.

Public Examination — Invasion of Privacy?

In the late 1960's survey of 104 specialists comparing their opinion of relative rank order and actual paper count in four peer-edited journals for the animal agriculture research units in the 48 contiguous-state stations, comments unsolicited and unidentifiable as to source were received by the author indicating that some scientists believed any examination of research competence was uncalled for and unnecessary; some implied it was an invasion of the area of academic freedom. More recently equally vigorous opposition has been expressed. At the time of initiation of the first objective survey of research competence in the early 1960's, the writer was greatly influenced by those views and as a result did not publish his findings. He initiated the studies as a private endeavor solely to answer objectively questions put by the highest circles of U.S. executive government and to which he was ashamed to answer as a matter of personal opinion. The death of President J. F. Kennedy brought to a close the detailed examination of agricultural research by the President's Science Advisory Committee, which had it been completed and a comprehensive report published then would have, if it developed as projected, contributed much to public understanding of the organizational structure, the competence, and the purpose of this nation's agricultural research establishment.

In the meantime comments have appeared in the science literature pro and con (6, 16, 28) about the basic competence of agricultural researchers and sometimes about the basic integrity of the organizational structure of which they are a part. Presumably as a result of these reactions, Congress stipulated in the appropriations enactments of the Food and Agriculture Act of 1977 even closer future surveillance by federal agencies of agricultural research, and centralized even further the decision-making process about the subjects of agricultural research and the scientific technology to be employed in their resolution. None of that influence is yet injected into the published record.

The Problem for the Public

The problem before us now is whether the directions taken for us by our federal Congress and our federal action agencies are the proper ones for optimum future service of agricultural research to the American public. The penalty of failure will be great and undeniably subject to wider recognition than will be the rewards of success. Unfortunately, government does not enjoy detached, disinterested examination of its own actions and has not authorized and is not likely to authorize lively research into the most effective and proper way for the public in its own interests to support agricultural research.

This examination of the output of technical journal articles and peer-edited scientific papers by the state agricultural experiment stations system of the United States, with special emphasis on one station, Illinois, for items of detail the national data do not provide, has summarized the situation for a unique period in U.S. history. Since World War II science and its application to public concerns have expanded at heretofore unprecedented rates. There are now signs of an imminent decrease in those rates, which in the face of the world's projected population expansion raises important questions of national policy for agricultural research. The data presented here close out a period of federal funding and reporting policy. The stage is set for future comparative studies of the effectiveness of new policies initiated at the end of the period covered in which the public and federal and state governments have a great stake.

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Appendix: Raw Data for Study IIc

The following table summarizes the raw data obtained for the study of full-length peer-edited articles published in 66 selected journals for the calendar years 1967, 1968, and 1969. The subject matters relate basically to departments or units in the Illinois Agricultural Experiment Station except that animal sciences combines the output of two Illinois departments and the animal production publications of the Veterinary Research unit of the University of Illinois College of Veterinary Medicine. No journals dealing with animal pathologies and their control were included in the journals selected for review. Subject matters not included in the responsibilities of the Illinois departments or units are listed under "other."

The journals reviewed (shown after the table) were developed from a list provided in 1970 by heads of departments and prominent scientists at the Illinois station. Estimates from fiscal year data indicated that approximately 37 percent of the national total of technical journal articles published by the state agricultural experiment stations for the period appeared in these journals. For Illinois the estimate was 36.5 percent.

Articles with multiple authors were credited proportionately to their employers without regard to author order; this procedure accounts for the fractional numbers in the table. Blanks appear in the table where either no publications were recorded for that subject matter or the subject matter was not clearly identified for the station, in which case the publication or proportionate share thereof was credited to "other." For normalizing the distribution of these observations and for statistical analysis, 0.5 was added to each observation and the square root transformation of that figure used.

The data are recorded here by states and by subject matters before that transformation was made. As described in the text, they represent an adequate sample for delineation of subject matter scientific publication output by the Illinois station. Whether they do so for any other state's output for a designated subject matter we were unable to test.

A rank array of the states based on the total number of publications credited to the agricultural experiment stations of the 50 states results in an order varying slightly from a rank order based on least square means of annual publications per subject matter unit given for the first 10 stations in Table 6. Based on the raw data totals for each station for the three years, the rank order for the top ten stations is California, Wisconsin, New York, Illinois, Michigan, Indiana, North Carolina, Iowa, Minnesota, and Oregon.

Full-Length Publications in 66 Peer-Edited Scientific Journals During 1967-1969
for the Agricultural Experiment Stations of Each State by Subject Matter

State	Subject matter															State total
	Agr econ	Agr engin	Agron	Anim scis	Entom	Food sci	Forest	Home econ	Hort	Plant path	Other					
Alabama	2.00	6.49	23.05	12.38	26.50	8.00	2.00	12.83	5.50	2.00	5.50	104.25				
Alaska			1.00									3.50				
Arizona	7.17	10.00	39.20	20.60	26.57		3.00	11.70	11.70	16.16	14.28	148.68				
Arkansas	4.67	1.33	20.84	39.99	7.00	1.00	1.00	6.33	25.25	25.25	1.33	112.74				
California	36.17	73.22	273.17	110.11	208.64	69.19	39.30	55.90	27.07	27.07	369.51	1,445.42				
Colorado	6.00	20.91	23.16	32.40	5.00	6.50	9.41	10.75	10.75	27.67	16.91	160.86				
Connecticut	6.33	4.00	22.00	36.16	28.50	.50	4.00	1.00	34.00	1.33	34.16	171.98				
Delaware			1.67	1.33	6.00			3.32	12.01	12.01	2.00	26.33				
Florida	8.33	6.33	64.90	61.96	22.00	18.42	3.00	17.66	62.49	62.49	35.53	306.62				
Georgia	2.50	10.19	40.85	81.96	24.50	23.41	1.00	20.42	6.33	6.33	9.45	276.20				
Hawaii	.33	8.33	26.43	10.00	15.25	7.67	5.00	12.00	12.00	13.17	13.50	111.68				
Idaho	1.50	3.83	25.09	6.50	3.50	6.00	2.25	5.75	5.75	5.75	2.50	54.02				
Illinois	25.50	28.78	93.68	131.26	48.33	41.67	2.11	46.57	53.65	53.65	9.92	495.42				
Indiana	34.28	20.64	70.98	117.58	36.67	2.75	15.28	53.15	63.34	63.34	20.02	446.85				
Iowa	6.50	25.68	82.08	74.31	11.33	45.54	6.67	7.00	37.54	37.54	31.18	342.54				
Kansas	4.90	7.50	46.53	58.90	44.34	16.16	1.00	9.16	9.16	8.25	22.67	236.01				
Kentucky	4.33	20.00	38.20	55.00	21.41	2.00	16.02	15.75	2.00	21.58	8.50	186.77				
Louisiana	4.00	9.75	10.66	16.61	44.94	4.20	9.83	1.83	9.83	25.66	11.57	180.05				
Maine	1.00	4.00	4.25	14.00	4.00	5.00	1.00	2.00	1.50	2.00	1.57	35.75				
Maryland	5.50	3.50	9.82	29.06	20.50		3.40	21.00	21.00	1.50	28.59	122.87				
Massachusetts	2.00	11.64	24.67	25.56	8.00	47.00	3.00	2.75	3.00	6.03	18.66	156.31				
Michigan	22.00	42.32	35.63	90.50	14.78	79.54	14.33	53.34	53.34	43.58	38.90	455.49				
Minnesota	20.50	11.67	50.77	59.84	30.33	17.00	6.94	8.51	8.51	57.83	41.08	325.47				
Mississippi		10.25	12.49	16.13	46.16	10.00	1.00	4.17	4.17	11.50	6.33	118.03				
Missouri	21.83	12.41	30.96	50.07	30.33	12.33	6.00	19.74	19.74	17.67	11.53	226.31				
Montana	2.50	2.66	15.46	2.00	2.50	1.00	13.44			1.00	31.17	59.79				
Nebraska	5.33	15.56	61.51	28.37	21.67	8.00	9.28	13.17	13.17	22.83	7.03	198.75				
Nevada		1.00	5.34	9.50			1.00	1.58	1.58	6.67	10.43	17.42				
New Hampshire			1.20	5.87		3.50	3.17	15.03	15.03	9.33	85.71	217.55				
New Jersey	4.00	4.75	21.33	26.58	31.00	9.00										
New Mexico		.50	13.50	9.33	12.50		2.00	2.00	2.00	63.06	57.36	42.33				
New York	13.50	16.16	121.07	127.22	95.76	52.00	17.41	15.00	15.00	23.06	73.58	619.04				
North Carolina	4.50	52.20	82.59	38.48	44.83	38.91	11.50	17.84	17.84	30.73	73.58	416.16				
North Dakota	1.33	7.83	30.10	6.03	6.00	1.00	1.00	1.33	1.33	5.40	5.40	65.02				
Ohio	9.66	23.14	21.25	84.22	43.50	3.33	4.11	5.17	5.17	16.42	31.08	243.13				
Oklahoma	12.16	23.80	25.13	42.80	16.35	2.00	7.00	2.50	2.50	12.67	21.69	169.10				
Oregon	14.50	5.37	38.58	18.31	44.00	42.77	2.75	20.77	20.77	31.25	54.16	314.79				
Pennsylvania	26.00	18.00	31.41	50.50	8.25	8.25	11.00	5.83	5.83	53.47	19.25	260.71				
Rhode Island		.50	6.90	3.40	5.33		3.00	11.00	11.00	8.00	1.66	37.79				
South Carolina		6.50	10.54	42.67	24.50	8.17	1.53	6.58	6.58	2.66	18.46	124.58				
South Dakota																
Tennessee	5.00	4.83	14.27	17.47	6.00		1.53			6.33	5.50	60.93				
Texas	1.00	5.50	14.63	24.50	8.17	2.50	8.67	.50	.50	2.00	12.00	82.14				
Texas	9.83	19.08	102.43	62.00	46.49		1.66	6.50	6.50	6.17	30.04	286.20				
Utah		3.50	20.33	15.63	1.00	1.00	4.50	2.00	2.00	1.67	11.00	88.63				
Vermont			6.00	2.00	4.50		2.00	3.50	3.50	1.66	4.00	24.66				
Virginia	4.81	6.28	35.48	55.43	33.00	5.83	13.33	10.03	10.03	28.49	33.24	220.02				
Washington	8.50	4.33	28.26	49.98	18.00	1.00	8.25	17.03	17.03	57.07	37.17	243.09				
West Virginia	.33	2.66	10.66	9.44	9.08	1.00	11.83	4.50	4.50	16.58	2.91	70.99				
Wisconsin	34.58	9.51	98.48	130.40	95.00	67.77	13.41	22.11	22.27	85.06	205.89	784.48				
Wyoming			2.50	9.66	5.00						5.83	26.66				
USDA	1.00	2.67									3,935.43	3,935.43				
Subject matter total	389.37	607.10	1,890.98	2,027.59	1,333.26	645.41	400.23	244.80	572.68	1,292.44	5,446.75	14,850.61				

Peer-Edited Journals Used in Study IIC

Agricultural Engineering
 Agronomy Journal
 American Economic Review
 American Journal of Agricultural Economics (formerly Journal of Farm Economics)
 American Journal of Sociology
 American Society for Horticultural Science Journal (formerly American Society for Horticultural Science Proceedings)
 American Society of Agricultural Engineers — Transactions
 American Society of Civil Engineers — Geotechnical Engineering Division Proceedings
 American Society of Civil Engineers — Hydraulics Division Proceedings
 American Society of Civil Engineers — Irrigation and Drainage Division Proceedings
 American Sociological Review
 American Wood Preservers' Association Proceedings
 Applied Microbiology
 Canadian Entomologist
 Canadian Journal of Agricultural Economics
 Cereal Chemistry
 Crop Science
 Econometrica
 Entomological Review (English translation, from U.S.S.R.)
 Federation Proceedings, Federation of American Societies for Experimental Biology
 Forest Products Journal
 Forest Science
 Genetics
 Horticultural Research
 HortScience
 Journal of Agricultural and Food Chemistry
 Journal of Agricultural Engineering Research
 Journal of American Dietetic Association
 Journal of Animal Science
 Journal of Bacteriology
 Journal of Consumer Affairs
 Journal of Dairy Science
 Journal of Economic Entomology
 Journal of Food Science
 Journal of Food Technology
 Journal of Forestry
 Journal of General Microbiology
 Journal of Heredity
 Journal of Home Economics
 Journal of Hydrology
 Journal of Insect Physiology
 Journal of Invertebrate Pathology

Journal of Milk and Food Technology
Journal of Nutrition
Journal of Reproduction and Fertility
Journal of Soil and Water Conservation
Land Economics
Lipids
Mycologia
Nematologica
Phytochemistry
Phytopathology
Plant and Soil
Plant Disease Reporter
Plant Physiology
Poultry Science
Regional Science Association
Rural Sociology
Silvae Genetica
Sociological Quarterly
Soil Science
Soil Science Society of America Journal
Textile Research Journal
Virology
Weed Science
Wood Science and Technology

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