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Introduction

A major body of literature reports the research which has been conducted to evaluate the returns to agricultural research. And a bibliography of publications which reports much of this work is presented by Norton and Davis in their recent review paper. Several major research evaluation studies have utilized a production function approach (cross-sectional or time series) and estimated research returns for aggregate agricultural production or for groups of agricultural commodities. Bredahl and Peterson, particularly, have conducted extensive cross-sectional analysis to measure returns to agricultural research in the U.S. for commodity groupings which include cash crops, poultry, dairy, and other livestock. They used published data series on input categories including land, machinery, labor, fertilizer, chemicals, seed, feed, pasture, and livestock groupings, from the 1969 U.S. Census of Agriculture and data on state research expenditures from the USDA annual Inventory of Agricultural Research. Norton, in as yet unpublished work, has updated the Bredahl-Peterson work using 1974 census data and examined the stability of the research coefficient for the commodity groups used by Bredahl and Peterson. Finally, Davis, in his recent Ph.D. dissertation, focused on evaluation of the stability of the coefficient on the

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research variable over time in aggregate U.S. agricultural production functions.

The above cited analyses and others show returns to agricultural research in the U.S. to be high, historically, and allocated fairly efficiently among commodity groups when returns are computed as a marginal internal rate of return to research investment. Though the marginal product for the research variable may well be declining, at least for some commodity groups, it is still much in excess of its cost. This excess is probably greatest for those high volume commodity groups for which research resulting in yield gains can be spread over large crop acreages or over large numbers of livestock and, therefore, over large volumes of output.

Thus, a wealth of information on returns to agricultural experiment station research expenditures exists for aggregate agriculture and for commodity groups of major commercial importance in the U.S. But, many of the investments made in agricultural research, and, consequently, many of the allocative decisions on research funding, are commodity-specific. It would, as a result, be highly desirable to obtain expanded perspective on and measurement of the returns to research expenditures made for individual agricultural commodities.[1/] And, since the major potential use of these estimates is to project the pay off for future research expenditures, it would be desirable to have such estimates for the most recent time period(s) possible. Of particular interest are crops such as corn, soybeans, and

[1/] There are several other important dimensions of agricultural research which also need evaluation. They include, among others, the distribution of research benefits over time and over various recipient groups. Also, of course, evaluations conducted in an ex ante (projective) mode are, for most uses, preferrable to ex post evaluations. And, most lines of non-commodity related agricultural research have received only scant economic evaluation.

wheat which are commodities for which very substantial research investments are being made by the State Agricultural Experiment Stations. Moreover, all three crops are of major economic importance in the North Central Region. Also of considerable interest are other major crops such as grain sorghum, rice and cotton and some "newer" crops with potential economic importance such as sunflowers.

There are a number of examples of commodity-specific research evaluations in the literature. Araji and associates at Idaho have recently undertaken work to measure the economic impact of wheat research in the western region of the U.S. And, Griliches and others have studied the impact on output of specific technologies which resulted from agricultural research. Griliches' work on the impact of hybrid seed corn, in particular, represents a pioneering work on commodity-specific technology assessment. These commodity-specific studies have generally employed a consumer-producer surplus approach to measuring benefits and have calculated an average rate of return based on an estimate of the value of inputs saved, past supply shifts, or scientists' estimates of future productivity increases resulting from additional research funding. In general, a production function approach appears to be a preferable methodology when one is interested in estimating a <u>marginal</u> rate of return to research while holding fertilizer, land, labor, and/or other inputs constant. Marginal internal rates of return to research investments for individual commodities can then be estimated and the implications for efficiency of allocation of research funds examined. We have undertaken to do this for corn, wheat and soybeans and the results are reported later in this paper. Before reporting the results of our production function analysis, however, we review briefly the highlights of the origin and development in the U.S. of corn, wheat and soybeans and report key data on production and usage trends for these crops. We do this for several reasons. First, we want to show that the objectives of agricultural research are diverse. Even the objectives of plant breeding research are diverse, including those of improvements in climatic adaptability, pest resistance, product quality, and adaptability to new production technology along with higher yields. Second, commodity research is a long-term investment. For example, current wheat breeding work builds on 160 years of previous work and organized corn and soybean breeding work precedes this century in its origin. Third, most production (yield increasing) research must be accompanied by some expansion in effective commodity markets (demand) or the economic return to this research will eventually be driven to such low levels that it will no longer be justified. Fortunately for U.S. farmers, corn, wheat, and soybeans have found major demand expansion outlets, particularly in export markets, in the 1970's.

Origins and Development of Corn, Wheat, and Soybeans in the U.S.

Current production and usage of corn, wheat and soybeans are the result of a long history of introductions and improvements due to plant breeding research. Improved production technology and husbandry have also contributed to higher volume production of these crops. In this section we review briefly highlights of some of the changes that have occurred in their breeding, production and usage.

Corn: Corn is considered to be indigenous to the Western Hemisphere (Inglett). Major changes in corn breeding, production and usage have occurred in the United States, however, since the first colonization. Before 1900, mass selection was the primary method used by public and private plant breeders for corn improvement. Progress was slow but open-pollinated varieties such as Reid Yellow Dent met the demands of a largely unmechanized agriculture (Alexander, Dudley, and Creech).

As early as 1880, W. J. Beal advocated that open-pollinated varieties be crossed because the cross tended to be higher yielding than the parents (Alexander, Dudley, and Creech). The papers by G. H. Shull (1908, 1909), however, marked the beginning of modern hybrid corn breeding (Jenkins). The ideas of Shull were implemented in breeding programs in 1916 and these programs were expanded in the 1920's. Their commercial use began in 1933 (Jenkins). By 1950 nearly all the corn raised in the Corn Belt was from hybrid seed. Most of the hybrids used resulted from double crosses until the mid-1960's when improved inbred lines permitted use of the single cross to become more widespread.

Hybrid corn has two major advantages over open-pollinated corn. The first is yield superiority. The second is that it permits rapid changes in the characteristics of corn which can be grown in response to changing physical and economic conditions. For example, disease resistance can be bred into new crosses as can be uniformity for mechanical harvesting. Also, the uses of corn have changed over time and hybrids have been tailored to meet the demands of the new uses. Among the specific objectives of corn breeders, in addition to higher yields, have been those of changing maturity dates, protein content, color, pest resistance, adaptability to new technology, etc. Many of these factors, of course, interact with yields as well.

It should be pointed out that while the most significant improvements in corn yields have undoubtedly come from plant breeding, increased production has also resulted from a number of other factors. These include: increased rates of fertilization, higher plant populations made possible by the higher fertilizer applications, use of herbicides and insecticides, improved moisture control (including irrigation) and improved mechanization resulting in more timely production and harvesting operations. These factors are, in large part, also the result of applied agricultural research and, as a group, they capitalized heavily until recently on cheap fossil fuel energy.

Turning to production, corn is grown in the 48 contiguous states in the U.S. with more than one-half of the total being raised in the Corn Belt. Total corn acreage declined from 100 million to 70 million acres over the period 1930 to 1978 while production increased by over 300 percent and yield by almost 400 percent (see Table 1). The share produced in the Corn Belt has increased over time. Though average yield per acre has advanced at a lower rate in the Corn Belt than in the rest of the country, the acreage has not declined as rapidly.

Prior to 1920 corn acreage in the United States had expanded continually. Land was plentiful and machinery improvements made it possible for one person to farm more acreage. When land became scarce scientists turned more toward yield improving technologies. As yields improved and production increased putting downward pressure on prices, the government undertook policies to reduce feedgrain acreage. As a result, part of this acreage was replaced by other crops such as soybeans and part became idle. Mechanical improvements which initially were concentrated in planting and cultivation became more pronounced in the harvesting and post-harvesting technology after 1940.

Approximately 85 to 90 percent of the corn acreage in the U.S. is now devoted to grain production and most of the rest to silage, hogging down, and grazing. About one-half of the corn grain raised is presently consumed on the farm where produced and the other one-half is sold. The percentage sold has increased continually over time. The quantity of corn grain exported has increased from less than one percent in 1920 to around 30 percent of U.S. production in recent years. Approximately 60 percent of the current production is fed to livestock domestically. This proportion has declined steadily over time with exports picking up the difference. In 1940, for example, 80 percent was fed to livestock and 5 percent exported. The total quantity of corn fed to domestic livestock has increased markedly, however, over the past fifty years as production increased severalfold. Slightly less than 10 percent of the corn produced is now used for food and industrial purposes and this percentage has remained fairly constant over time.

Effective research to increase yields and/or to reduce per unit production costs for corn is important both for the retention of a competitive position for U.S. feedgrains in export markets and to hold the cost structure of the domestic livestock sector to an acceptable level. Because of the large acreage of corn grown, particularly in the Corn Belt, even modest decreases in per unit production costs translate into major economic benefits.

Wheat: Wheat is believed to have originated in the Middle East and was among the first plants cultivated by man (Inglett). From prehistoric times to the present wheat has remained a crop of primary economic importance to the world.

Wheat was brought from Spain to the West Indies by Christopher Columbus on his second voyage in 1492. It was brought to Mexico in 1510 and shortly thereafter arrived in the southwestern United States. In the late 16th and early 17th centuries it was planted by settlers along the North Atlantic coast of North America (Peterson). Many immigrants from Europe brought

Table 1. Corn Acreage, Yield, and Production in the U.S.

Year	Acreage Harvested* (1000 Acres)	Yield Per Acre Harvested* (Bushels)	Production* (1000 Bushels)	Year	Acreage Harvested* (1000 Acres)	Yield Per Acre Harvested* (Bushels)	Production* (1000 Bushels)
1930	101,465	20.5	1,757,297	1955	79,530	40.6	3,229,743
1931	106,866	24.1	2,229,903	1956	75,634	45.7	3,455,283
1932	110,577	26.5	2,578,685	1957	72,616	47.1	3,422,331
1933	105,918	22.6	2,104,725	1958	73,327	51.8	3,800,863
1934	92,193	15.7	1,146,734	1959	83,529	51.3	4,281,316
1935	95,974	24.0	2,001,367	1960	82,117	53.0	4,352,668
1936	93,154	16.2	1,258,673	1961	57,634	62.4	3,597,803
1937	93,930	28.1	2,349,425	1962	55,726	64.7	3,606,311
1938	92,160	27.7	2,300,095	1963	59,227	67.9	4,019,238
1939	88,279	29.2	2,341,602	1964	55,369	62.9	3,484,253
1940	86,738	28.4	2,212,367	1965	55,392	74.1	4,102,867
1941	86,186	31.0	2,435,307	1966	57,002	73.1	4,167,608
1942	89,021	35.2	2,849,340	1967	60,694	80.1	4,860,372
1943	94,455	32.1	2,724,530	1968	55,280	79.5	4,449,542
1944	97,234	33.2	2,909,553	1969	54,574	85.9	4,687,057
1945	87,625	32.7	2,868,795	1970	57,358	72.4	4,151,938
1946	87,585	36.7	2,868,795	1971	64,047	88.1	5,641,112
1947	82,888	28.4	2,354,739	1972	57,421	97.1	5,573,320
1948	84,778	42.5	3,005,078	1973	61,894	91.2	5,646,806
1949	85,595	37.8	3,237,749	1974	65,357	71.4	4,663,631
1950	81,818	37.6	3,074,914	1975	67,222	86.2	5,797,048
1951	80,729	36.2	2,925,758	1976	71,300	87.9	6,266,359
1952	80,940	40.7	3,291,994	1977	70,872	90.7	6,425,457
1953	80,459	39.9	3,209,896	1978	69,970	101.2	7,081,849
1954	80,186	38.1	3,057,891				

* Yield and production represent equivalent grain yields on total acres harvested for all purposes, for the years 1930 to 1960. Yield and production represent only corn harvested for grain for the years 1961 to 1978. The major part not harvested for grain was harvested for silage. In 1961 this represented 6,117 thousand acres, in 1970, 8,158 thousand acres; and in 1978, 8,587 thousand acres.

wheat seeds with them. Other species and varieties have been brought in by agronomists, plant breeders, and others so that most of the major wheat species have now been tested in the U.S.

Man has had a significant effect on the evolution of wheat for many centuries but the major changes began 160 years ago with the first deliberate breeding of wheat by P. Shiriff in 1820 in Haddington, Scotland (Lelley).

In the United States, the great diversity of conditions of wheat production and market uses has led to a variety of objectives in wheat breeding. Higher yields, earliness of maturity, winter hardiness, resistance to drought, heat, lodging, shattering, stem rust, leaf rust, bunt, and other diseases, quality for milling and bread making, hessian fly resistance, etc., have all received attention from plant breeders.

The major commercial wheat classes in the U.S. are hard red winter wheat, hard red spring wheat, soft red winter wheat, white wheat, durum wheat, and red durum wheat.[2/] Most of the important varieties in the late 1900's and early twentieth century were introductions from other countries. The predominant hard red winter varieties were "Turkey" wheats introduced into the United States around 1873. The Canadian varieties Red Fife and Marquis introduced in 1860 and 1912 were important early hard red spring wheats. Fultz was a major soft red winter, Pacific Bluestem a major white, and Kubanka a major durum wheat (Reitz). At first by selection and later by breeding these varieties were improved upon over time.

Since 1919 the USDA has surveyed wheat varieties every 5 years in the U.S. Very few varieties remain popular more than 10 years and in some cases

[2/] These classes are not based on the growth habit of the plant, though it varies some between classes, but (a) on whether it is sown in the autumn or spring and (b) on the characteristics of the grain produced which determines its utilization(s).

shifts to new varieties occur within a 3 to 4 year period. Higher yields, greater resistance to disease and lodging, and key characteristics relating to quality are the main causes for this turnover of varieties.

Before 1940, breeders placed primary emphasis on increasing the strength of stems, winter hardiness, yield, and to a lesser extent, disease resistance. Since 1940, greater emphasis has been placed on breeding for resistance to disease (Peterson). Straw strength, lodging and shattering resistance have also received attention to facilitate mechanical harvesting. Most recently, attention has focused on improving wheat quality (Lelley).

Wheat is produced in most parts of the U.S. but the major producing areas are the Great Plains with two-thirds of total U.S. production. Wheat has a comparative advantage over other crops on the plains where moisture is low and variable. Wheat farms tend to be more specialized and large-scale from the Great Plains on west. In the areas further east wheat is grown in rotation on smaller, more diversified farms.

The most important class of wheat in the U.S. is hard red winter with more than 60 percent of total production. The soft winter wheat region has declined relative to other regions since the 1920's. Trends in U.S. wheat production, acreage, and yield are shown in Table 2. In general, acreage has declined but yield increases have more than offset this decline causing total production to increase. Acreage has declined 9 percent since 1930, but yields have increased 123 percent. Certain temporary phenomena such as World War II and the Korean War have caused short-term aberrations in these trends.

Year to year fluctuations in production are due primarily to weather although fertilizer, insects and diseases, and other factors have had some effects. Longer run yield increases have resulted from adoption of both

Table 2. Wheat Acreage, Yield, and Production in the U.S.

Year	Acreage Harvested (1000 Acres)	Yield Per Acre Harvested (Bushels)	Production (1000 Bushels)	Year	Acreage Harvested (1000 Acres)	Yield Per Acre Harvested (Bushels)	Production (1000 Bushels)
1930	62,637	14.2	886,522	1955	47,285	19.8	934,731
1931	57,704	16.3	941,540	1956	49,784	20.2	1,004,272
1932	57,851	13.1	756,307	1957	43,806	21.7	950,662
1933	49,424	11.2	552,215	1958	53,404	27.4	1,461,714
1934	43,347	12.1	526,052	1959	52,665	21.4	1,126,682
1935	51,305	12.2	628,227	1960	52,643	25.9	1,363,443
1936	49,125	12.8	629,880	1961	51,571	23.9	1,232,359
1937	64,169	13.6	873,914	1962	43,688	25.0	1,091,958
1938	69,197	13.3	919,913	1963	45,506	25.2	1,146,821
1939	52,668	14.1	741,180	1964	49,762	25.8	1,283,371
1940	52,988	15.3	813,305	1965	49,560	26.5	1,315,603
1941	55,642	16.9	943,127	1966	49,613	26.3	1,304,889
1942	49,200	19.8	974,176	1967	58,353	25.8	1,507,598
1943	50,648	16.6	841,023	1968	54,765	28.4	1,556,635
1944	59,309	18.2	1,078,647	1969	47,146	30.6	1,442,679
1945	65,167	17.0	1,107,623	1970	43,564	31.0	1,351,558
1946	67,105	17.2	1,152,118	1971	47,674	33.9	1,617,789
1947	74,519	18.2	1,358,911	1972	47,284	32.7	1,544,936
1948	72,418	17.9	1,294,911	1973	53,869	31.7	1,705,167
1949	75,910	14.5	1,098,415	1974	65,613	27.4	1,796,187
1950	61,607	16.5	1,019,344	1975	69,641	30.7	2,134,833
1951	61,873	16.0	988,161	1976	70,771	30.3	2,142,362
1952	71,130	18.4	1,306,440	1977	66,216	30.6	2,036,318
1953	67,840	17.3	1,173,071	1978	56,839	31.6	1,798,712
1954	54,356	18.1	983,900				

improved varieties and better cultural practices. Mechanization has facilitated timeliness of operations. Farmers' decisions to increase or decrease acreage have been primarily due to the relationships between the price of wheat and the cost of producing it as well as the price/cost relationships for competing crops. Government price supports and acreage restrictions have played a key role in these decisions.

Wheat is used primarily for human food and each type of wheat has a particular food use. Per capita consumption of wheat has declined over time in the U.S. but this has been offset by an increased population to maintain a fairly stable level of annual domestic food consumption of about 600 million bushels. Increases in production in recent years have been absorbed by the export market and, since 1964, by increased use of wheat for feed. Exports of total U.S. wheat production have increased from 23 percent in 1919 to 60 percent in 1978.

Effective research to improve wheat quality has direct benefits to U.S. consumers as does research to reduce production costs. In general, however, research which increases yields probably needs to be evaluated mainly in terms of its value in export markets where competition occurs with foreign suppliers and, thus, where the marginal pricing (valuing) of U.S. produced wheat actually occurs. But, since yield increases usually also result in lower per unit production costs, benefits of yield increasing research accrue to both domestic consumers and producers. Since wheat, along with rice, is a major source of human food on a worldwide basis, the benefits from research which are transferable (and transferred) to other regions and other countries of the world are multiplied over a broad acreage base.

Soybeans: Soybeans are thought to have originated in the north and central part of China (Morse, 1950). The first published account of the plant in the U.S. appeared in 1804 (Johnson and Bernard). Piper and Morse (1923), Morse (1950), Probst and Hartwig (1973) and Hartwig (1973) have presented accounts of the early history of the soybean in the United States. The Perry expedition to Japan in 1854 brought back two types of soybeans, one of which is believed to have been the Mammoth variety which was the most important soybean grown in the U.S. in the early 1900's. Piper and Morse reported that not more than eight varieties were grown in the U.S. prior to the numerous introductions by the U.S. Department of Agriculture beginning in 1898.[3/]

Ball classified 23 varieties of soybeans in the U.S. in 1907. Two of these, Haberlandt and Tokyo, remained important varieties in the Virginia-North Carolina region until the mid-1940's (Hartwig, 1973). During the 20 year period from 1907 to 1927 more than 200 lots of seed were introduced by the USDA from China, Japan, Korea, Siberia, India, Indonesia, and Vietnam. These introductions were obtained through consuls, missionaries, seedsmen and others. A few of them were found suitable for production and assigned names. The primary consideration was suitability for forage production.

In 1927 the USDA received a collection of material including two varieties, Palmetto and CNS, from a research station near Nanking China. This material proved very useful in the development of varieties adapted to production in the southern states. Morse and Dorsett collected 4,578 lots of seed on an expedition to China, Korea and Japan during the period 1921-1931.

[3/] These eight varieties are Ito San, Mammoth, Butterball, Buckshot, Kingston, Guelph, Eda, and Ogemaw.

Morse and Cartter described 101 soybean varieties in the 1937 Yearbook of Agriculture. Of these, 67 were introductions from Asia or natural crosses that had occurred in introduction, 31 were selections from introductions and three were crosses made in the U.S. Approximately 60 percent were used mainly for forage and only 14 seed producing varieties were being grown on any appreciable acreage.[4/] Beginning in 1929 the use of soybeans by oil crushing mills led to a demand for seed varieties high in oil content. It was not until 1940, however, that acreage of seed varieties exceeded that of forage varieties.

Soybean varietal development received a boost in 1936 with the establishment of the U.S. Regional Soybean Industrial Products Laboratory at Urbana, Illinois. A cooperative research program was organized with the agricultural experiment stations in the 12 North Central states. In 1942, the work related to industrial uses of soybeans was moved to Peoria, and the remaining part at Urbana was renamed the U.S. Regional Soybean Laboratory. This laboratory was then expanded to include 12 southern states and soybean pathological work was initiated.

Since 1942 over 125 varieties have been registered first by the American Society of Agronomy and more recently by the Crop Science Society of America. A primary factor in the prolific varietal development is the response of soybeans to length of photoperiod. As a method of describing this responsiveness to day length, ten maturity groups have been established for identifying regions of adaption for soybean varieties in the U.S. and Canada.

[4/] Dunfield, Illini, Macoupin, Mancha, Mandarin, Mandel, Mukden, Richland, and Scioto were the principal varieties grown in the North Central states for seed production while Arksoy, Haberlandt, Mammoth Yellow, Tokyo, and Woods Yellow were the main varieties in the South. (Source: Hartwig, 1973).

Groups 00, 0, and I are adapted to the more northern latitudes of the continental U.S. and Canada while succeeding groups through group VIII are adapted farther south. Each maturity group contains a range of 10-15 days in maturity and one variety in each group is used as a standard to which other varieties are rated in days earlier or later in maturity (Hartwig, 1973). Since 1949, a germplasm collection has been evaluated and maintained at Urbana, Illinois for material of group IV or earlier maturity. Material from groups V through VIII have been evaluated and maintained at Stoneville, Mississippi.

An important factor affecting yields in soybeans is resistance to disease and insects. Although a large number of soybean strains were introduced into the United States, only a few produced moderate seed yields. Consequently, the varieties available today can be traced to a small number of parents.[5/] This means that genetic diversity has probably declined over time increasing the vulnerability of the soybean crop to insects and diseases. Fortunately, many lines from more diverse crosses have been maintained in the germplasm collections at Urbana and Stoneville. These represent a source of genes for potential pest resistance as new problems arise.

There is little doubt that over the past 30 years the amount of plant breeders' time devoted to breeding in disease and insect resistance has increased relative to that devoted to developing higher yielding varieties adapted to specific latitudes. The disease Phythophthora Rot was first recognized in soybeans in 1948. As was mentioned earlier, resistance

5/ In the northern states six varieties of Manchurian origin form the exclusive background for varieties grown on 95 percent of the total acreage and are in the background of the other 5 percent. The southern varieties have somewhat more diverse backgrounds but one variety is in the background of 60 percent of the southern varieties (Johnson and Bernard).

to that disease was transferred to several varieties through backcrossing. Tracy of group VI maturity released in 1973 became a popular variety during the 70's because of its resistance to several races of Phytophthora. The soybean Cyst Nematode was first recognized in soybeans in 1954 and has become a problem in several states. A number of varieties such as Custer released in 1967, group IV; Dyer released in 1967, group V; Pickett released in 1965 and Pickett 71 released in 1971, group IV, are all resistant to some races of Cyst Nematode. Forrest released in 1972, group V, is resistant to root rot as well as Cyst Nematode. In the last few years several new varieties have been released which are resistant to new strains of Cyst Nematode such as Bedford in GroupV and Franklin and Centennial in group IV. Attempts are also being made to transfer resistance to foliar or pod feeding insects such as the Mexican Bean Beetle.

As each new disease or insect is identified and new varieties resistant to it are developed, additional pests are identified. The value of the research which has gone toward maintaining the yield levels achieved by earlier varieties is substantial and often goes unrecognized. Soybean breeding over the past 35 years has been a continual process of breeding for increased production efficiency as well as for resistance to pests.

While new soybean varieties were being developed, yield increases and acreage expansions were resulting in rapid production increases in the United States. Soybean production has risen from 14 million bushels in 1930 to over 1843 million bushels in 1978 (Table 3). The average yield has approximately doubled over that period and the acreage has grown from about 1 million acres to 63 million acres. Table 3 as well as the above discussions highlights the fact that increased soybean production has resulted from a combination of acreage expansion and yield increases. Biological factors such as the development of new varieties for various latitudes and the breeding of disease resistance into varieties have been major factors determining the area in which soybeans can be grown and the existing yield potential. The fact that soybean acreage has expanded and yields have increased is an indication that economic relationships have been favorable enough to encourage farmers to plant them on a large acreage with yield improving practices.

In the early 1920's soybeans were included in the rotations of the southeastern states to help control the cotton boll weevil (Goldberg). By the mid-20's the Corn Belt had taken over the lead in soybean production as the crop began to replace some of the acreage previously devoted to corn oats, and hay. Lower market prices for corn as well as government programs designed to reduce the output of feed grains made soybeans attractive as a production alternative in the Midwest (Houck). For example, acreage restrictions were placed on corn in the 1930's and on corn, wheat, and cotton at various times since then. The expansion in the Delta region has been partly due to the replacement of cotton acreage by soybeans. In addition, soybeans have replaced corn and small grains in the south and have been planted on newly cleared and drained acreage. At the same time, the change from horses to mechanized power reduced the acreage needed for oats and hay. Soybeans were planted on a portion of those "freed up" acres.

On the demand side, the increased population and higher incomes since World War II have strengthened the demand for animal protein resulting in a strong demand for soybean meal as a high protein feed. Soybean oil has been in strong demand in both the domestic and foreign markets. The partial

Table 3. Soybeans for Bean Acreage, Yield, and Production in the U.S.

Year	Acreage Harvested (1000 Acres)	Yield Per Acre Harvested (Bushels)	Production (1000 Bushels)	Year	Acreage Harvested (1000 Acres)	Yield Per Acre Harvested (Bushels)	Production (1000 Bushels)
1930	1,074	13.0	13,929	1955	18,620	20.1	373,682
1931	1,141	15.1	17,260	1956	20,620	21.8	449,251
1932	1,001	15.1	15,158	1957	20,857	23.2	483,425
1933	1,004	12.9	13,509	1958	23,993	24.2	580,250
1934	1,556	14.9	23,157	1959	22,631	23.5	532,899
1935	2,915	16.8	48,901	1960	23,655	23.5	555,085
1936	2,359	14.3	33,721	1961	27,003	25.2	678,554
1937	2,586	17.9	46,164	1962	27,608	24.2	669,186
1938	3,035	20.4	61,906	1963	28,615	24.5	699,165
1939	4,315	20.9	90,141	1964	30,793	22.8	700,921
1940	4,807	16.2	78,045	1965	34,449	24.5	845,608
1941	5,889	18.2	107,197	1966	36,546	25.4	928,481
1942	9,894	19.0	187,524	1967	39,805	24.5	976,439
1943	10,397	18.3	190,133	1968	41,391	26.7	1,106,958
1944	10,245	18.8	192,121	1969	41,337	27.4	1,133,120
1945	10,740	18.0	193,167	1970	42,249	26.7	1,127,100
1946	9,932	20.5	203,395	1971	42,701	27.5	1,175,989
1947	11,411	16.3	186,451	1972	45,698	27.8	1,270,630
1948	10,682	21.3	227,217	1973	55,796	27.7	1,547,165
1949	10,482	22.3	234,194	1974	52,368	23.2	1,214,802
1950	13,807	21.7	299,249	1975	53,579	28.9	1,547,383
1951	13,615	20.8	283,777	1976	49,358	26.1	1,287,560
1952	14,435	20.7	298,839	1977	57,612	30.6	1,761,755
1953	14,829	18.2	269,169	1978	63,003	29.2	1,842,647
1954	17,047	20.0	341,075				

replacement of butter by margarine, for example, gave the demand for soybean oil a boost as did donations to foreign countries under PL 480.

Price supports were first placed on soybeans during World War II but acreage restrictions have never been in effect (Probst and Judd). In the early 1950's soybean processing technology improved which further strengthening the demand for soybeans (Houck).

It is evident that a number of factors have combined to provide a favorable economic climate for soybean production in the United States. The most important factors over the past 20 years have probably been the continual increase in demand for high protein feeds as well as oil, both in the U.S. and abroad. Yields have been somewhat variable over time and have generally been higher in the North Central region than in the South. The latter fact is due to a number of causes, among them the higher level of insects, diseases, weeds, and double cropping in the South. Yields in the North Central region currently average about 2 bushels per acre higher than in the rest of the U.S.

Effective soybean research is needed to retain the cost effectiveness for this crop in existing domestic and foreign markets. In addition to servicing these markets for high protein feeds and edible oils, research and market development efforts are being undertaken to expand production of soybean varieties well suited for direct human consumption in foreign markets (particularly Japan) and in the U.S. And, the results of research in this area will bear watching and evaluation.

Production Function Analysis

Earlier we mentioned the desirability of conducting "production function" type analysis to estimate the marginal products and internal rates of return for "commodity specific" research expenditures. The results of such analyses for corn, wheat and soybeans are reported below.

Model, Variables and Data

We have taken the cross-sectional production function approach to estimation for the three individual crops and obtained measurements on input categories comparable to those developed for broader commodity groups by Bredahl and Peterson.[6] The functional form used for each crop is the familiar Cobb-Douglas production function. Specification of individual variables in the functions is shown in Appendix A. Data which permits use of these input variables in crop specific formulations of production functions are scarce because certain inputs such as machinery and labor are typically employed on several enterprises on the same farm. Many farms raise both soybeans and corn, and often other crops as well, and there is very limited information on how machinery and labor use is split between these crops.

Since the U.S. Census of Agriculture does not report production input categories for specific agricultural commodities, we undertook to find alternative data sources from which we could develop commodity-specific production function formulations using individual states as observations. One source of such data is that provided in the nationwide set of farm enterprise budgets developed by Krenz, et. al., in the National Economics Division, ESCS, USDA. These so-called FEDS budget data have been developed annually since 1974 for all production areas in the U.S. for which the several major farm commodities are produced commercially. The FEDS enterprise budget data are developed drawing heavily on survey data for

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[6] Our input and output variables are, however, all represented as state aggregates for each of the included states. Bredahl and Peterson converted all variables, except research expenditures, to a "per farm" basis assuming that individual farms were the relevant "decision" units. For several reasons, including the one that some farms produce all three crops, corn, wheat and soybeans, we have chosen to use "state totals."

each major substate production area, though in some cases such areas are specified as an entire state.[7] We have weighted and aggregated these enterprise data for 1977 in a manner so as to develop category totals for each state included in our analysis.

While the "FEDS" budgets are readily available as a data source, they are not without some serious shortcomings for production function analysis. For example, the machine and labor inputs for a specific enterprise budget include, as is desirable for our purposes, only the machinery and labor that are used for that enterprise. But, for each crop, these input categories have a high degree of multicollinearity among the states because budgets are typically based on a fairly similar complement of machinery and a fairly common set of commercial production practices. Moreover, the machinery and labor input categories are highly correlated with land because each acre of land used for production of a specific crop has a similar package of machinery and labor inputs applied to it. Thus, high intercorrelations exist between these input categories for the population of states included in our analysis. And, the aggregated budget data do not depict variance which is proportional to that present among input categories on individual farms. But, this is also true for state-level data acquired or developed from other sources. Thus though the above mentioned higher intercorrelations between production input categories cause problems in estimating production functions using state aggregate categories of land, labor, and machinery as independent variables, this problem increasingly exists independent of the FEDS set of data.

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[7] These budgets are based largely on periodic "cost of production" sample surveys conducted by ESCS. The data represents machinery technology for 1974 but fertilizer quantities, pesticide expenditures and other input prices are for 1977. Per acre physical quantities are provided for nitrogen, phosphate and potash fertilizers and for lime.

Much of the per acre variance in input categories between state subregions, states and multi-state regions has disappeared over time as commercial farmers have developed farming operations which are highly mechanized and fairly standardized using chemical fertilizers and pesticides, etc. And, very little unemployed or underemployed labor remains on U.S. farms. This suggests that much of the earlier day variance between production areas in the use of at least some farm inputs has vanished as the shift to mechanized and otherwise modernized production methods on commercial farms in the U.S. has become virtually complete. And, this phenomenon will be reflected in the input data whatever their source.[8/] If, in fact, labor, machinery and land inputs are approaching a relationship of technical complements in the production process, the only feasible solution to the statistical estimation problem caused by multicollinearity may be that of using a single input category as a proxy for the several traditional inputs, or alternatively, converting each of the several input categories into a single variable (dollars) and using the aggregate value of this new variable.

The research variable included in the production functions for 1977 is an average of annual 1970-72 research expenditures for each crop from the CRIS data. Centered on 1971, the annual research expenditures are thus effectively lagged six years for the 1977 production function estimates.[9/]

8/ For example, the following simple correlations exist between land, labor, and machinery on a per farm basis for aggregate cash grain in the 1969 and 1974 Agricultural Census data:

1969	Machinery	Land	1974	Machinery	Land
Land	0.77		Land	0.90	
Labor	0.46	0.80	Labor	0.73	0.61

9/ Actually, of course, the returns which we estimated and attribute to these annual research expenditures are determined in part by prior period capital investments in research facilities, research scientists and research based knowledge. Thus, one could not expect a similar flow of returns to annual research expenditures in the absence of these prior year investments. And, it is important to retain the perspective of a stock of research capital that is being serviced (and to some extent, augmented) by a set of annual expenditures. It is to variance in these annual research expenditures among states that variance in the value of output is being associated in our analysis.

Research expenditures for corn average $330 thousand with a range of more than $1 million for the 23 states included in the analysis. Iowa, Indiana and Illinois are the top three states in corn research expenditures. These states are also the top soybean research states along with Arkansas. Soybean research expenditures average $211 thousand for the 26 states included in the analysis with a range of $500 thousand.[10/] Kansas and North Dakota are the top wheat research states in terms of expenditures. The mean wheat research expenditure is $185 thousand for the 34 states included in the analysis, with a range of $868 thousand. Because the benefits of research are not neatly contained within the boundaries of the states in which the research is performed, we undertake later to measure the spillover effects of research into other states.

A list of data sources used in estimating the production function is included in Appendix Table B.

Regression Results

Initial production functions were specified for each crop for 1977 using state aggregates as observations in order to estimate total crop value as a function of land, rainfall, fertilizer, chemicals, pesticides, labor, machinery expenses, and research expenditures.

These production functions yielded equations with high $\bar{R}^2$s (.996, .965 and .985 respectively for corn, wheat and soybeans) but with extremely unreliable coefficients for most variables. For corn only the fertilizer

[10/] Earlier it was mentioned that the regional USDA research laboratory in Illinois makes a significant contribution to soybean research. USDA expenditures for soybean research in 1971, exclusive of USDA funds spent at S.A.E.S., totalled $3.77 million. This compares with total expenditures of $5.49 million made in all S.A.E.S. research programs and $5.22 million by the 26 states included in our analysis. Thus, USDA research on soybeans is a significant part of the total public research program for this commodity.

and rainfall variables had significant parameters, for wheat only fertilizer and for soybeans only land and rainfall. A likely explanation for these statistically unreliable estimates can be found in the high intercorrelations among independent variables shown in Table 4. The correlations between land and both labor and machinery are extremely high and the correlations between land and fertilizer, chemicals and research expenditures are only modestly lower. In addition, a number of other input variables have high intercorrelations. In fact, among the independent variables, only the rainfall variable has low correlations with the others. Rainfall is not significant in the wheat equation but it is difficult to determine a single critical weather variable for wheat due to the presence of both spring and winter wheat. Moreover, growing seasons, crop maturity dates and weather patterns all vary significantly between individual spring wheat production areas and between individual winter wheat areas. Thus, a more sophisticated depiction of the influence of weather on wheat production is probably needed if it is to have statistically significant explanatory power.

Before attempting to deal with the problem of multicollinearity, an effort was made to account for major differences in land quality among regions through a set of crop specific regional slope dummies on the land variable. States included in the regional dummy variables were different for each crop (see Table 5). No significant differences were found for corn but the Northern and Southern Plains regions showed significantly lower quality land than the Corn Belt region for wheat. And, the Southern and Delta regions showed lower quality land than the Corn Belt for soybeans.

Table 4. Correlation Coefficients for Independent Variables in the Production Functions for Corn, Wheat and Soybeans.

Corn	Land	Fertilizer	Labor	Research	Rain	Chemicals
Fertilizer	.947					
Labor	.977	.932				
Research	.842	.844	.772			
Rain	.482	.349	.464	.284		
Chemicals	.971	.952	.937	.843	.422	
Machinery	.972	.926	.994	.753	.484	.936

Wheat	Land	Fertilizer	Labor	Research	Rain	Chemicals
Fertilizer	.860					
Labor	.974	.873				
Research	.807	.797	.779			
Rain	.024	-.189	.093	-.122		
Chemicals	.767	.609	.765	.602	-.134	
Machinery	.990	.868	.976	.790	-.001	.780

Soybeans	Land	Fertilizer	Labor	Research	Rain	Chemicals
Fertilizer	.731					
Labor	.987	.786				
Research	.857	.622	.861			
Rain	.280	-.020	.184	.093		
Chemicals	.929	.727	.925	.896	.244	
Machinery	.995	.766	.995	.856	.255	.929

In an effort to reduce the multicollinearity problem mentioned above, the land, labor, and machinery variables were value weighted and added together.[11/] Land quality dummy variables were no longer included because the use of land price weights was assumed to pick up at least some of the land quality differences. Functions were reestimated for corn, wheat, and soybeans. While the land-labor-machinery aggregate was highly significant in the wheat and soybean functions, it was not significant in the corn equation. The chemicals variable increased in significance in all cases while rainfall and research both increased in significance in the wheat equation. A large amount of multicollinearity still exists, however, among chemicals, fertilizer, research, and the land-labor-machinery aggregate variable.

Another set of regressions was run in which all "traditional variables," land, labor, machinery, chemicals, and fertilizer, were value weighted and aggregated. This input aggregate was included in a production function with rainfall and research as the other independent variables (see Table 6). In this case the traditional variable aggregate is highly significant for each crop. Rainfall was significant at the 95 percent level for corn and wheat. Research had a positive coefficient in all cases and was significant at the 95 percent level for wheat, and the 90 percent level for soybeans. The research coefficients were of roughly the same magnitude for each of the three crops.

Additional regressions were run in which a "spillover" variable was added in an attempt to pick up the spillover effects of research across state boundaries. While spillover of research occurs for all three crops to some

[11/] See data sources listed in Appendix B for price weights. Combining or eliminating variables reduces multicollinearity but can result in specification bias. The latter reduces one's confidence in the results to some extent.

Table 5 States Included in Land Dummies

<u>Wheat</u>:	34 States.
Slope 1.	KY., MD., N.Y., N.C., PA., TENN., VA.
Slope 2.	ALA., ARK., GA., MISS., S.C.
Slope 3.	COLO., KANS., OKLA., TEX.
Slope 4.	MONT., NEBR., N. DAK., S. DAK.,
Slope 5.	ARIZ., CALIF., IDAHO., N. MEX., OREG., WASH.
Land	ILL., IND., IOWA., MICH., MINN., MO., OHIO.
<u>Corn</u>:	23 States.
Slope 1.	DEL., KY., MD., N.J., N.Y., N.C., PA., TENN., VA.
Slope 2.	COLO., KANS., NEBR., TEX.
Land	ILL., IND., IOWA., MICH., MINN., MO., N. DAK., OHIO., S. DAK., WIS.
<u>Soybeans</u>:	26 States.
Slope 1.	ALA., GA., OKLA., S.C., TENN., TEX.
Slope 2.	DEL., KY., MD., N.J., N.C., VA.
Slope 3.	ARK., LA., MISS.,
Land	ILL., IND., IOWA., KANS., MICH., MINN., MO., NEBR., OHIO., S.DAK., WIS.

Table 6. Research Production Functions *

	Land Labor Machinery Chemicals Fertilizer	Rain	Research	Constant	$\bar{R}^2$
Corn	.72	.33	.198	1.98	.883
	(5.16)	(3.80)	(1.20)	(1.09)	
Wheat	.75	.02	.27	-.17	.899
	(8.69)	(.94)	(3.37)	(-.14)	
Soybeans	.66	.26	.28	-4.63	.886
	(5.25)	(3.50)	(1.74)	(-3.25)	

* Numbers in parentheses are t-values.

extent, it is thought to be most pronounced or at least of a different form for soybeans because varieties are very latitude specific. Varieties raised in Iowa, for example, are also raised in Pennsylvania. Any simply constructed spillover variable is somewhat arbitrary and open to criticism. The specification used in this study is described in Appendix A. The results of adding a spillover variable to the production functions are shown in Table 7.

These results indicate that inclusion of the research spillover variable improved the soybean and wheat functions substantially but the crude specification of the spillover variable used for corn was not a particularly useful addition to the function for that crop.

The specified research spillover variable for soybeans is highly significant. It has a t-test of 4.51 and the adjusted R^2 for that equation increases from 0.886 to 0.940. The research coefficient itself decreased from 0.28 to about 0.235. Other specifications for the soybean equation were tried with the spillover variable included and the coefficient of the research variable remained highly significant and stable.

The addition of a research spillover variable for wheat increases the $\bar{R}^2$ for the wheat function slightly from that of table 6 and it strengthens the significance of the rain and research variables in the equation while leaving the coefficient on the "traditional inputs" variable highly significant.

In 1977 wheat yields were 9 bushels greater, soybeans 2 bushels greater, and corn about the same in the North Central region compared to the rest of the U.S. An additional regression was run for each of these crops in which a slope dummy was included on the research variable to determine if a significant difference exists between the 13 North Central states and the remaining states. The results indicate that no significant difference exists in the research coefficient for the two groups of states.

Table 7. Research Production Functions With Research Spillover Variable.*

	Land Labor Machinery Chemicals Fertilizer	Rain	Own Research	Research Spillover	Constant	$\overline{R}^2$
Corn	.68	.34	.20	.06	1.89	.878
	(4.26)	(3.76)	(1.22)	(.53)	(1.02)	
Wheat	.67	.021	.27	.14	.249	.914
	(7.75)	(1.07)	(3.57)	(2.49)	(-.22)	
Soybeans	.64	.15	.24	.33	-7.95	.940
	(6.93)	(2.63)	(2.01)	(4.51)	(-6.25)	

*Numbers in parentheses are t-values.

Marginal Products and Rates of Returns

One should not place excessive confidence in the exact size of the research coefficients reported in Tables 6 and 7 due to the possible specification error resulting from the aggregation of several input variables. Also, we are measuring returns to an annual flow of commodity-specific research expenditures when a portion of these returns might reasonably be attributed to prior period investment in the research system and/or to investments in more basic or general purpose research. Moreover, our measure of output is for a single year, 1977, and it will vary some between years. With those cautions in mind, the equations in table 7 were utilized to compute the marginal products of experiment station research. Estimates of national marginal products of research for corn, wheat, and soybeans are obtained by multiplying the research coefficient for each commodity by its respective average product of research.[12/] These estimates were then prorated by dividing them by three to take account of extension and other (mainly private and USDA) research. Arguments supporting this procedure are presented in Bredahl and Peterson but alternative proratings of benefits are easy to make and it seems unlikely that the proportional contribution of agricultural experiment station research is less than that of either private research or extension. An exception might be the case of soybeans where substantial public research is also being conducted by USDA. The resulting long-run marginal product approximations are shown in Table 8.

The calculation of internal rates of return requires that the future returns be discounted. A mean lag of six years is assumed for research on each of these crops. This is consistent with empirical studies, such as Evenson's, on the length of the lag. Breeding research probably has a somewhat longer lag but other types of crop research probably have a shorter lag.

[12/] Geometric mean levels of output and research are used in calculating the average products.

Table 8. Marginal Products and Internal Rates of Return*

	Marginal Products	Assumed Lag	IRR(%)
Corn	97	6	115
Wheat	59	6	97
Soybeans	103	6	118**

*Calculated from the equations in table 7 which include spillover variables for all 3 crops. IRRs calculated from equations in table 9 (without spillover variables) differ only slightly in magnitude from these.

**One might wish to discount this IRR for soybeans further to compensate for the substantial amount of research conducted by USDA.

Two facts stand out with regard to the IRR's shown in Table 8. First, they are extremely high and, even if discounted severely for possible errors, suggest underfunding of public research for these crops.[13/] Second, the IRR's are of the same general order of magnitude for each crop. The latter fact suggests that research dollars probably are being allocated fairly efficiently among the three crops. Moreover, the interstate allocation of research dollars for the three crops appears generally consistent with the relative economic importance of the three crops at least for those states where these specific crops are of major economic significance.

Summary and Conclusions

The regression results presented in this paper illustrate the data problems involved in trying to use the productions function approach in individual commodity research evaluations. Yet, decisions relative to the allocation of research funds are often commodity-specific and even specific to such research functions as plant breeding, soil fertility, work, mechanization of production and/or harvesting, disease and/or insect control, work on improved marketing systems, etc. And, where feasible, efforts need to be undertaken to evaluate the results of these and other lines of agricultural research.

On the basis of previous research as well as that reported here, we believe one can reasonably say that the returns to research for corn, wheat and soybeans continue to be high and well in excess of their investment costs. These high returns occur partly because the crops involved are large-acreage,

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[13/] Previous authors have used varying formulas for computing the IRR's to research (Davis). Differences in these formulas stem from the assumptions made about the distribution of benefit over time. In this study the assumption was made that all benefits occur in the sixth year after the research expenditures which should provide underestimates of the IRR's.

high-value crops for which there have been rapidly expanding markets. And, the research has permitted U.S. producers to compete successfully for these markets. Research funding appears to have been allocated reasonably efficiently among these three crops in the early 1970's. The exact magnitude of returns, however, is open to some question because of data problems and because the contributions of other research and extension can only be allocated in very general terms.[14]

Of the production functions which we estimated, the best equations are probably those shown in Table 8. In equation form they are:

1. Corn: $Y = 1.89\, X_1^{.68}\, e^{.34X_2}\, X_3^{.20}\, X_4^{.06}$

   Where: Y = value of corn output;

   X_1 = value aggregate of traditional land, labor, machinery and fertilizer inputs;

   X_2 = deviation from normal July rainfall;

   X_3 = own state research expenditures;

   X_4 = spillover of research expenditures from other states.

2. Wheat: $Y = -.25\, X_1^{.67}\, e^{.02X_2}\, X_3^{.27}\, X_4^{.14}$

   Where: Y = value of wheat output;

   X_1 = value aggregate of traditional land, labor, machinery and fertilizer inputs;

   X_2 = deviations from normal July rainfall;

   X_3 = own state research expenditures;

   X_4 = spillover of research expenditures from other states.

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[14] Many would argue that one cannot separate the contributions to productivity of research and education (extension and other informational inputs). Even so, we believe that our estimates indicate high returns to the public research-education system for these three commodities as of 1970-72.

3. Soybeans: $Y = -7.95\, X_1^{.64}\, e^{.15X_2}\, X_3^{.24}\, X_4^{.33}$

Where: Y = value of soybean output;

X_1 = value aggregate of traditional land, labor, machinery and fertilizer inputs;

X_2 = deviations from normal July rainfall;

X_3 = own state research expenditures;

X_4 = spillover of research expenditures from other states

In general, we conclude that for individual crops a production function formulation is probably preferable which aggregates most traditional production inputs[15/] which are highly correlated with land but which provides for separate specifications of major weather effects and research expenditures, the latter including an operational measure of spillover between geographical areas. Moreover, it would be interesting to attempt the construction of an additional input variable reflecting the degree of technical sophistication employed in production but which might be less highly correlated with land. It is our intent to devote additional effort to improvement of the weather, and spillover variables and to the possible construction of a new "technology" expressive input variable.

[15/] Such aggregation is probably neither feasible nor desirable for those commodities for which there are big differences in production technology (particularly in degree of mechanization) between states or other geographical areas considered. One must make a judgment as to whether the reduction in multicollinearity following aggregation of variables will be outweighed by any resulting specification bias.

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Appendix A--Variables For Individual Crop Production Functions

Variable

1. Output -- Total Value of Crop Sold

   Multiplied each state's production by national average price. USDA publication Crop Production, Annual Summary gives production data and USDA publication Crop Values gives price data.

2. Land -- Area Planted to Crops

   Found in USDA publication Crop Production Annual Summary.

3. Labor -- Value of Labor

   Multiplied hours of machinery labor from "FEDS" budget by farm wage rate for the U.S. found in USDA publication Farm Labor.

4. Fertilizer - Average U.S. prices for N, P, and K used to sum up N, P, & K into one variable. These prices were found in USDA publication Costs of Producing Food Grains, Feed Grains, Oilseeds, and Cotton.

5. Chemicals - Value of herbicides and insecticides from FEDS crop budgets deflated by the price of the appropriate herbicide and insecticide for each crop. For example, the corn herbicide value was deflated by the ratio of the national to the state price of Atrazine.

6. Machinery -- Sum of (1) fuel and lube (2) service flow of machinery stock and (3) custom hire of machinery.

    (1) Fuel and lube -- Value of fuel and lube from crop budgets deflated by the weighted national average price of gasoline and diesel fuel divided by the weighted state price of gasoline and diesel fuel in each state.

    (2) Ownership costs from FEDS budgets

    (3) Custom hire from FEDS budgets.

7. Weather -- July rainfall (deviations from normal) for corn and soybeans
Annual rainfall (deviations from normal) for wheat

8. Soils -- Slope dummies on land variables based roughly on 1957 Yearbook of Agriculture land groups, for wheat and more aggregated groups for soybeans and corn.

9. Research -- Total expenditure on research for particular commodity from Inventory of Agricultural Research FY 1970-1972 average.

10. Research Spillover -- Soybeans: research expenditures on soybeans for other states at the same latitude which fall within the same recognized "soybean group". If only a portion of a state is included in the same "soybean group", a production weighted proportion of that state's research is included in the spillover variable.

    Corn and wheat: corn and wheat research expenditures for bordering states which fall within the same geoclimatic region. The wheat regions were based on those delineated by Davis and the corn regions were based on corn maturity zones.

If only a portion of a bordering state is included within the same geoclimatic region, a production weighted proportion of the state's research is included in the spillover variable.

Appendix Table B--Data Sources

Data Sources

1. United States Department of Agriculture, Agricultural Statistics, 1971, Washington, D. C.

2. ________, 1977 Annual Prices Summary, Crop Reporting Board, ESCS, USDA, June 1978.

3. ________, Cost of Producing Selected Crops in the United States - 1976 - 1977 and Projections for 1978, ESCS, USDA, March 1978.

4. ________, 1978 Crop Production, Annual Summary, Crop Reporting Board, ESCS, USDA, January 1978.

5. ________, Crop Value 1976-1977-1978, Crop Reporting Board, ESCS, USDA, February 1978.

6. ________, Farm Labor, Crop Reporting Board, ESCS, USDA, Feb. 1978.

7. ________, Farmers' Use of Pesticides, ESCS, Ag Economic Report No. 418, 1978, Washington, D. C.

8. ________, Inventory of Agricultural Research FY 1970, Vol. II, Science and Education Staff, 1970.

9. ________, Inventory of Agricultural Research, F.Y. 1971, Vol. II, Science and Education Staff, 1971.

10. ________, Inventory of Agricultural Research, F.Y. 1972, Vol. II, Science and Education Staff, 1972.

11. ________, Federal Enterprise Data, System, 1977 budgets, ESCS, USDA, (obtained from Ronald Krenz, Oklahoma State University).

12. ________, The Yearbook of Agriculture 1957, Soil, USDA, Washington, D.C.

13. ________, unpublished data on deviation from normal July and annual rainfall provided by Michael Weiss at USDA.