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An Analysis of Agricultural Research in Relation to the Increasing Demand for Agricultural Products

Production Research Report No. 104

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An Analysis of Agricultural Research in Relation to the Increasing Demand for Agricultural Products

By BYRON T. SHAW, *Office of Administrator, Agricultural Research Service*

The President's Science Advisory Committee¹ estimated that world food production in the next 20 years needs to be increased 50 percent. Daly and Egbert² estimated that U.S. crop production for domestic use and export would need to be increased annually 1.9 percent and livestock production for domestic use 1.7 percent to keep pace with expected demands in the next 15 to 20 years.

Total crop production can be increased in three ways: Cultivate more acres so long as we have unused land, change the composition of production (grow more corn in Iowa instead of Mississippi), and obtain higher yields per acre. With adequate crops we can increase livestock production by adding more animals, by changing the composition of output (more chickens and less beef cattle), and by augmenting the yield per animal.

All these ways of expanding agricultural output will be used as the demands for agricultural products become greater, but there are limits to increasing acres. The acres now withheld from production through Government programs would meet the demands for agricultural products for about 5 or 6 years if output per acre and per animal were not increased. To be sure, we have additional millions of acres that could be used for crop production, but the cost of doing this on a large scale makes this a poor alternative to increasing yield per acre through research.

We need to analyze the current progress in agricultural research to see if improved practices are being developed fast enough to keep up with the increasing demands for agricultural products.

First, let us look at some recent advances in agriculture that were made possible by research in

the past 50 years. In table 1 is shown the increased production per acre or per breeding unit of some principal agricultural commodities between 1947-51 and 1962-66. Crop yields in this 15-year period are up 39 percent, with an average annual compound increase of 2.22 percent. Corn has the largest average annual increase of 4.25 percent, followed by rice and cotton. Soybeans has the smallest increase of 1.14 percent. All livestock production is up 30 percent, with an average annual increase of 1.76 percent. Milk production is up 54.4 percent and pork production 16.7 percent.

Our look back was encouraging in terms of future needs. If we could maintain the same progress in the next 15 years as was achieved in the last 15 years, we could meet our crop and livestock needs with fewer acres than we are now farming. Is the look ahead equally encouraging? How should we project the increase in crop yields? Will they continue to increase at an average annual rate of 2.22 percent? Or will the rate be higher? Possibly it will slow down. To make matters worse, yields may even level off or decrease. We may get some guidance to answering these questions by examining past progress over shorter time intervals.

In table 2 is shown the average annual compound change in productivity of five commodities by 5-year intervals from 1932 to 1966. It is apparent from these data that the change in productivity with time is unique for each commodity and that there are difficulties in projecting the rate of progress in the next 5 years on the basis of what has happened previously. Rice and egg production have the most consistent trends in the last 15 and 20 years, respectively. If the present trend continues, one would expect that a ceiling on egg production per layer would be reached in about 1971. Will this happen? It would be easier to answer this question if we had some knowledge of the factors responsible for the particular relationship in evidence from 1932 to 1966 between egg production per layer and time.

¹ U.S. PRESIDENT'S SCIENCE ADVISORY COMMITTEE. THE WORLD FOOD PROBLEM. A REPORT OF THE PRESIDENT'S SCIENCE ADVISORY COMMITTEE. 127 pp. Washington, D.C. 1967.

² DALY, R. F., and EGBERT, A. C. A LOOK AHEAD FOR FOOD AND AGRICULTURE. Agr. Econ. Res. XVIII, No. 1, pp. 1-9. 1966.

TABLE 1.—Average increased productivity of some principal U.S. agricultural commodities between 1947-51 and 1962-66

Commodity	Productivity in—		Increase between 1947-51 and 1962-66	Annual compound increase
	1947-51	1962-66		
YIELD PER ACRE				
Crops:			<i>Percent</i>	<i>Percent</i>
Corn, grain..... bushels..	36.5	68.1	86.6	4.25
Wheat, all..... do.....	16.6	25.9	56.0	3.01
Potatoes, white..... hundredweight..	137.6	198.1	44.0	2.46
Tobacco, all..... pounds..	1,240.8	1,948.6	57.0	3.05
Cotton lint..... do.....	279.6	499.8	78.8	3.95
Rice..... do.....	2,211.6	4,073.8	84.2	4.15
Soybeans for beans..... bushels..	20.5	24.3	18.5	1.14
Beans, dry edible..... pounds..	1,014.6	1,278.4	26.0	1.55
Sugar beets for sugar..... tons..	14.5	17.3	19.3	1.18
MILK PER COW				
Livestock:				
Dairy cows (milk)..... pounds..	5,194	8,022	54.4	2.94
EGGS PER LAYER ANNUALLY				
Poultry (eggs)..... number..	169	216	27.8	1.65
PORK PER SOW FARROWED				
Swine (pork)..... pounds..	1,372	¹ 1,601	16.7	1.03
Indexes:				
Crop yields per acre.....	100	139	39	2.22
Livestock production per breeding unit.....	100	¹ 130	30	1.76

¹ 1962-65.

TABLE 2.—Average annual compound change in productivity of 5 U.S. commodities by 5-year periods from 1932-36 to 1962-66

Commodity	1932-36	1937-41	1942-46	1947-51	1952-56	1957-61
	to 1937-41	to 1942-46	to 1947-51	to 1952-56	to 1957-61	to 1962-66
	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>
Corn, grain..... bushels per acre..	¹ 3.47	3.24	1.68	2.78	5.08	4.65
Potatoes, white..... hundredweight per acre..	3.30	3.94	8.34	3.01	3.08	1.27
Rice..... pounds per acre..	.02	-1.31	1.70	4.13	4.06	4.19
Milk..... pounds per cow..	1.70	.61	1.94	1.89	3.61	3.35
Eggs..... number per layer..	2.29	1.94	2.75	2.20	1.70	.98

¹ 1934 and 1936 data omitted from 1932-36 average for corn because drought greatly reduced yield.

Egg Production per Layer

Of one thing we can be sure. The ceiling on egg production per layer at any time is set by the then known information about egg laying and the factors affecting egg laying. The nearness to the ceiling at any time will depend on the average

producer's knowledge and managerial ability, economic conditions, weather, and other factors.

It would be helpful if we could chart what egg production per layer would have been possible year by year if there had been maximum practical utilization of the then known information about egg laying. This is shown in figure 1.

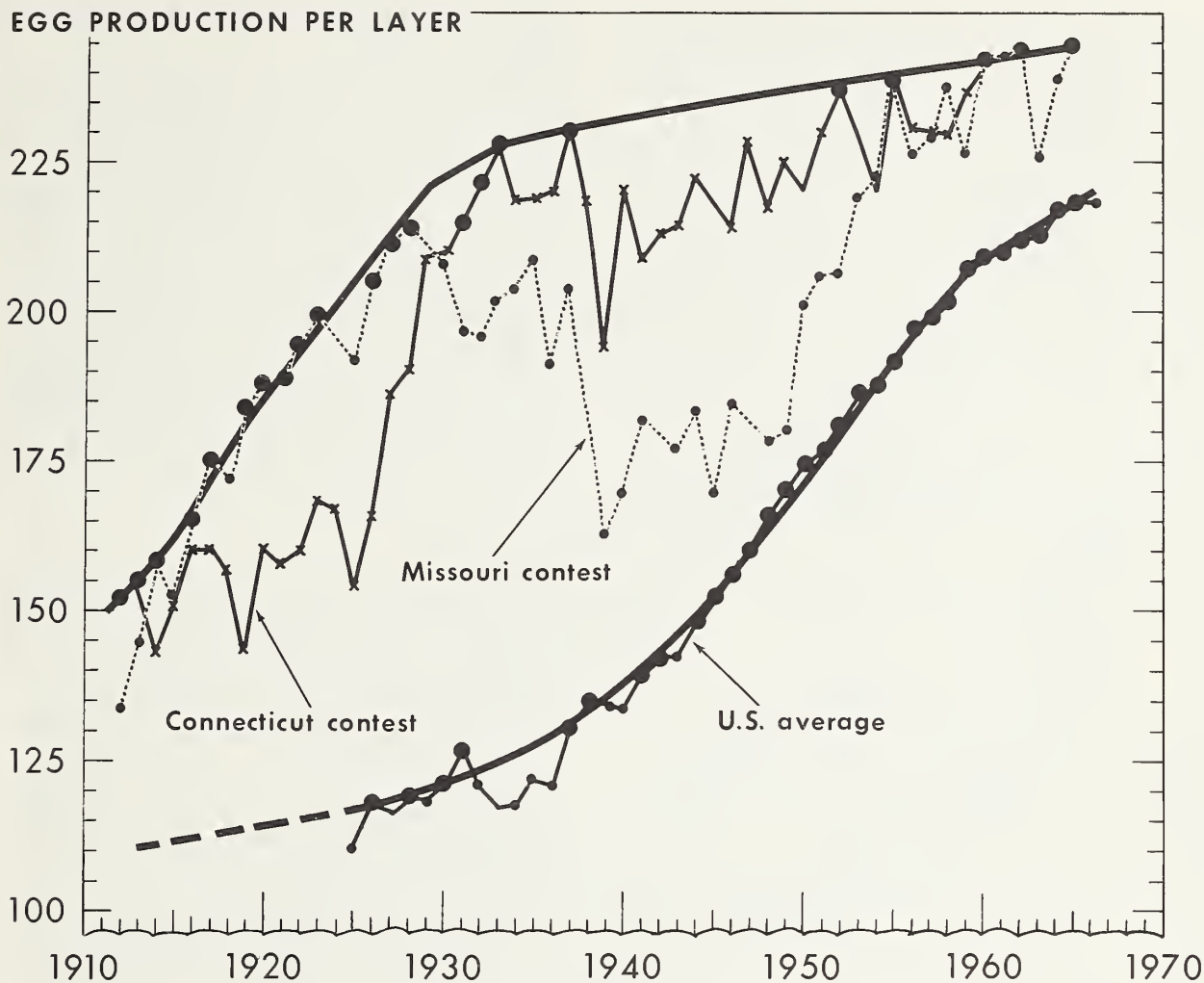


FIGURE 1.—Egg production per layer.

The average annual egg production per layer in the Connecticut Egg Laying Contest from 1912 to 1960³ and the Missouri Egg Laying Contest from 1912 to 1965⁴ is shown in figure 1. Hens are entered in these contests from all over the United States. The objective is to break previous records. Each succeeding large dot represents a maximum value not previously achieved in either contest. The smooth curve, fitted by sight to these maxima, is considered to reflect possible annual egg production per layer under most favorable conditions using available information. It represents in ef-

fect the frontier of knowledge about egg laying. It is apparent that in many years actual production in the contests fell below the frontier of possibilities.

The U.S. average egg production per layer⁵ is also shown in figure 1. Here again a smooth curve has been drawn through maximum values and represents progress in average production per layer in the best years.

It is apparent from the upper smooth curve in figure 1 that knowledge about egg laying expanded rapidly between 1912 and 1935 and has advanced more slowly since then. The average an-

³ Data furnished by F. A. Ryan, Department of Poultry Science, University of Connecticut. This contest was discontinued in 1961.

⁴ Data furnished by D. M. Hughes, Poultry Experiment Station, Mountain Grove, Mo.

⁵ Number of eggs produced annually divided by average number of hens and pullets of laying age on hand during year.

nual compound increase in egg-production possibilities between 1912 and 1933 was 1.95 percent and between 1933 and 1965 it was 0.22 percent. The rapid rise in U.S. average egg production per layer between 1935 and 1955 is simply a delayed response to the advance in knowledge between 1912 and 1933. The slower increase since 1955 is a reflection of the slower advance in knowledge since 1933. The large backlog of unused information available to farmers in 1935 has been decreasing year by year (distance between curves). Extension and other educational programs have been effective. The U.S. average egg production per layer was 89 percent of the contest average in 1965, whereas it had been only 54 percent in 1930.

It seems clear that increasing production through education is becoming a more limited alternative to research and that U.S. average egg production per layer will rise very slowly in the future unless knowledge about egg laying is advanced much more rapidly than it has been in the last several years.

Before passing judgment on our research program, let us examine other situations.

Corn Production per Acre

In figure 2, trends in corn production per acre have been analyzed by the same methods as in figure 1 for egg production. The corn production possible with full use of research information is represented by data from the Iowa Corn Yield Test from 1923 to 1965.⁶ The plotted points for this test are the average yields for the current year for those entries in each district having the highest 2-year average yield (previous and current year). (I first determined the entry in each district having the highest average yield for 2 consecutive years and then recorded the current year's yield for that entry. I next averaged these current year values for all districts. These averages were usually for 12 districts up to 1963, but in some years the averages were for fewer districts depending on which fields were harvested. In 1964 the experimental plan was changed so that the State was divided into six districts. The subdivision of district 4 into bottomland and upland made seven districts in all.) Again the frontier of possibilities under most favorable conditions, such as weather and disease control, is represented by the smooth curve fitted to maximum values.

Average corn yields per acre for Iowa from 1910 to 1966 and for the United States from 1900 to 1966 are also shown in figure 2. The smooth curves fitted to maximum values represent what the aver-

age farmer could have done if all environmental factors were optimum.

From the shape of all three curves in figure 2, it is apparent that the rise in average farm corn yields is a delayed response to the advance in knowledge about corn growing developed in research. The first rise in the top research curve from 1923 to 1935 was due to the development of hybrid corn. The rise in average corn yields in Iowa (middle curve) from 1937 to 1945 was due to the adoption of these hybrids. Six percent of Iowa farmers were growing hybrids in 1935, 98.7 percent in 1942, and 100 percent in 1945. Because of soil deterioration, U.S. average corn yields actually decreased between 1906 and 1940. With the partial adoption of hybrids, 46 percent in 1942, yields were restored to what they should have been, and with the further adoption of hybrids, 91.1 percent in 1956, yields showed the same kind of increase that had been obtained in Iowa about 10 years earlier.

The second rise in the top research curve from 1933 to 1963 was due to (1) the development of improved hybrids, which had better disease and insect resistance and which responded to increased levels of fertility; (2) the use of higher rates of fertilization, particularly nitrogen; and (3) weed control. In 1966 the fields on which the yield tests were conducted received on an average 200 pounds of nitrogen per acre.

Average corn yields in Iowa rose again in 1958 in response to the second increase in research knowledge. The long delay was due to the slowness of Iowa farmers to start using fertilizers in appreciable quantities. In 1959 only half the acres planted to corn were fertilized, and they received on an average only 28 pounds of nitrogen per acre.⁷ Nitrogen used in Iowa in 1964 was more than three times that used in 1959.

Since 1956 the U.S. average corn yields are responding to the advance in research knowledge concurrently with the Iowa average yields rather than with the time lag evident in earlier years. It is interesting that U.S. average yields are now gaining on Iowa average yields. In part this is due to the higher percentage of corn acreage now grown in the Corn Belt. In addition, we are doing a better job of adapting and disseminating research information on a national basis than we did earlier.

What about the future? If research knowledge about corn growing continues to advance at the rate reflected by the top research curve in figure 2, the average corn yields will continue to rise also.

⁶ Data furnished by Crops Research Division, U.S. Department of Agriculture, and Iowa Agricultural Experiment Station.

⁷ IBACH, D. B., ADAMS, J. R., and FOX, E. J. COMMERCIAL FERTILIZER USED ON CROPS AND PASTURE IN THE UNITED STATES, 1959 ESTIMATES. U.S. Dept. Agr. Statis. Bul. 348, 201 pp. 1964.

CORN, BU. PER ACRE

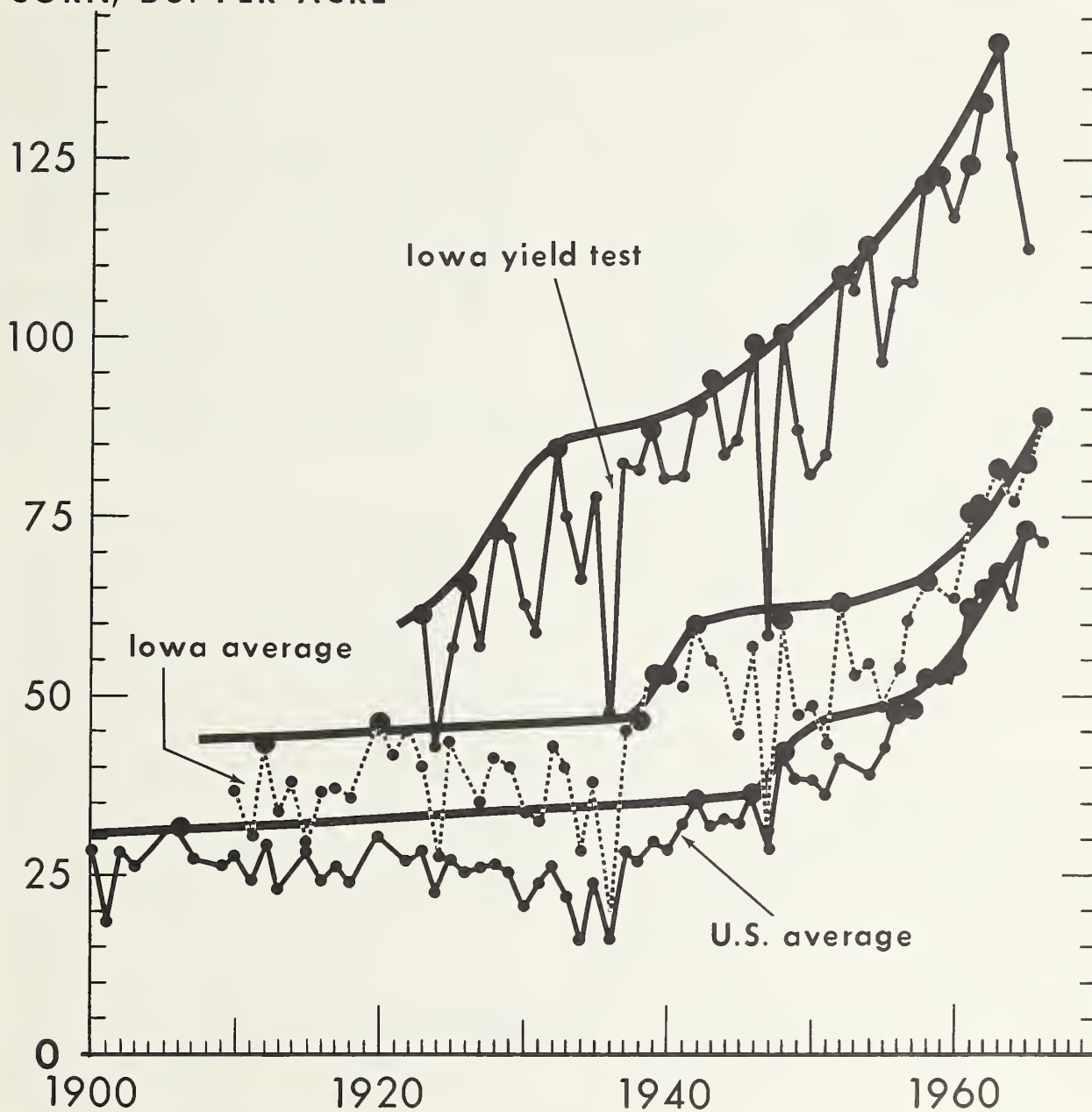


FIGURE 2.—Corn production per acre.

However, a point of caution is in order. It may be questioned whether this research curve will continue to rise at the same rate. In the district yields used to obtain the averages in figure 2, the highest yield in any district was 164 bushels in 1956, 166

bushels in 1962, and 165 bushels in 1963. Yields in 1964 and 1965 were lower. Thus for 10 years the maximum yield has not increased. It may be that research knowledge about corn growing is not advancing.

Potato Production per Acre

The research frontier in potato production per acre advanced rapidly between 1943 and 1951 but slowed down after 1951, as shown in the top curve in figure 3. Highest yields per acre in the Maine Variety Test⁸ increased from 383 cwt. in 1943 to 553 in 1951 and 590 in 1964. This advance was due primarily to the development of high-yielding varieties with disease resistance and to insect and weed control.

Conditions favoring the adoption of new information were such that average yields in Maine and the United States followed closely on the research advance between 1943 and 1951. Average yields increased in Maine 35.2 percent and in the United States 80 percent in this period. Since 1950 they have not increased in Maine. Because average yields in some other States, notably Washington, have risen since 1950, the U.S. average has continued to rise but at a slower rate than during 1943-50. In the 15-year period from 1950 to 1965 U.S. average yields increased 34.6 percent, whereas they had increased 80 percent in the 7-year period from 1943 to 1950.

It appears that U.S. average potato yields will reach a plateau in the near future unless research knowledge is developed more rapidly than in the last 15 years.

Pork Production per 100 Pounds of Feed

The picture presented for pork production per 100 pounds of feed in figure 4 is not very encouraging. The research frontier, as represented by the top 10 percent of pigs on performance tests,⁹ increased steadily from 1920 to 1950, making a gain of 16.2 percent in 30 years. This was an average annual compound gain of only 0.5 percent. The average annual compound gain from 1950 to 1960 was only 0.07 percent. The U.S. average¹⁰ in 1952 was 15.3 percent above that in 1921, an advance almost equal to that shown in the top curve for the same period. In most years, however, the U.S. average has been well below what appears to be possible. In 1965 it was below that achieved in 1916.

⁸ Data furnished by Crops Research Division, U.S. Department of Agriculture, and Maine Agricultural Experiment Station.

⁹ Data furnished by Animal Husbandry Research Division, U.S. Department of Agriculture. Experiments reported in *Journal of Animal Science*, *Journal of Agricultural Research*, and experiment station bulletins were used as data sources. The plotted points are 5-year averages centering on the year shown. From 200 to 800 pigs were included in each period.

¹⁰ U.S. ECONOMIC RESEARCH SERVICE. 'CHANGES IN FARM PRODUCTION AND EFFICIENCY. U.S. Dept. Agr. Statis. Bul. 236, 50 pp. 1964 and 1967.

Rice Production per Acre

The research frontier in rice production per acre is represented in figure 5 (top curve) by the highest yield in the Louisiana Variety Test.¹¹ Yields in this test have advanced rapidly in recent years. The yield of 4,115 pounds per acre in 1929 was highest until it shot up to 5,467 pounds in 1950 and 6,535 pounds in 1960. These recent gains have been due to the development of shorter, stiff-stemmed, high-yielding varieties that responded to higher levels of fertilization and also to better disease, insect, and weed control.

Farmers rapidly utilized the new information and rice yields increased greatly in both Louisiana and the United States. Even though average rice yields follow so closely on the research advance, it seems likely that they will continue to increase. But if recent gains are to be maintained for any length of time, the research frontier will have to be advanced beyond the level reached in 1960.

Wheat Production per Acre

Conditions for growing wheat in the United States vary considerably from the humid East to the dry lands of the Plains and winter precipitation areas of the Northwest. Data from the Indiana Variety Test (1956-66)¹² and the Ohio Variety Test (1942-66)¹³ were selected to represent possible wheat production per acre in the Eastern United States, using the known information. In the Indiana test, varieties were grown at five locations in all years and at as many as nine locations in some years. In the Ohio test, the number of locations varied between eight and 15. In each test the high yield at each location was determined for each year. The high yields at all locations in each State each year were averaged to get an average high yield for the State for the given year. In figure 6, values were plotted for those years in which the average high yield exceeded any value previously achieved. The smooth curves for the Indiana and Ohio Variety Tests thus represent what was possible under most favorable conditions.

A similar procedure was used for the Washington Variety Test.¹⁴ In Washington, varieties were grown at two locations each year.

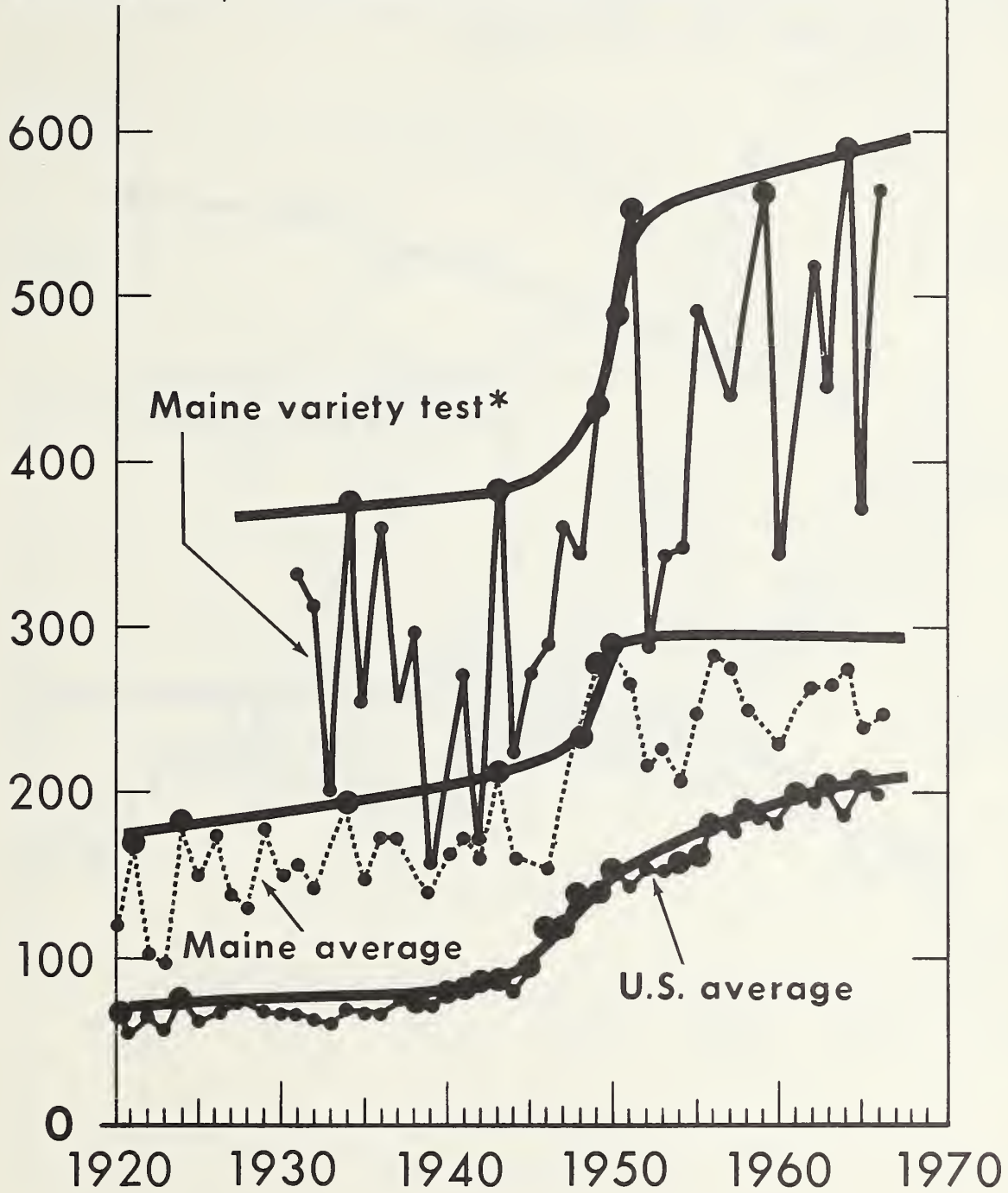
¹¹ Data furnished by Crops Research Division, U.S. Department of Agriculture, and Louisiana Agricultural Experiment Station.

¹² Data furnished by Indiana Agricultural Experiment Station.

¹³ Data furnished by Ohio Agricultural Experiment Station.

¹⁴ Data furnished by Crops Research Division, U.S. Department of Agriculture, and Washington Agricultural Experiment Station.

POTATOES, HUNDREDWEIGHT PER ACRE



* HIGHEST YIELD.

FIGURE 3.—Potato production per acre.

PORK (LIVEWEIGHT), LB. PER 100 LB. OF FEED

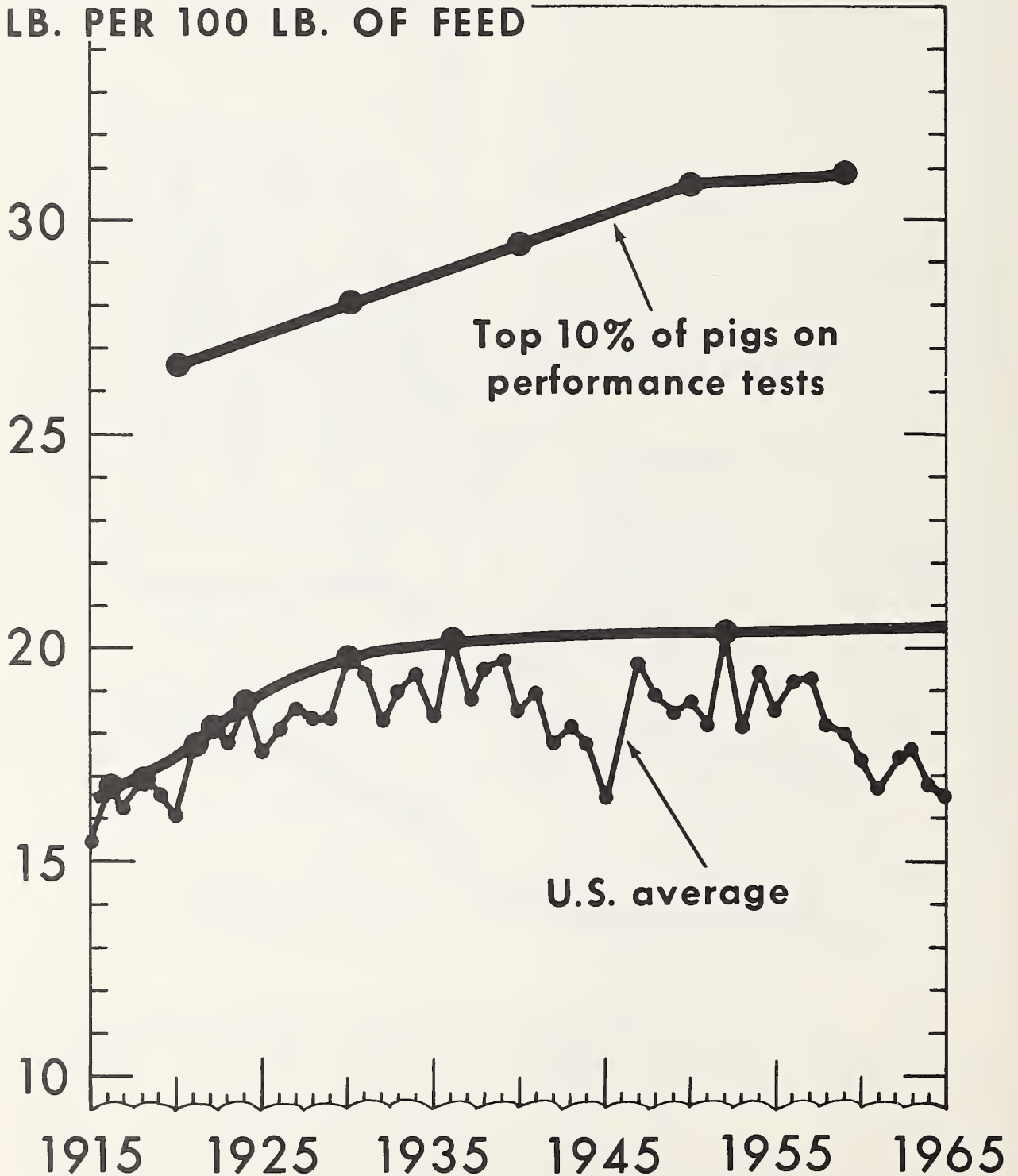
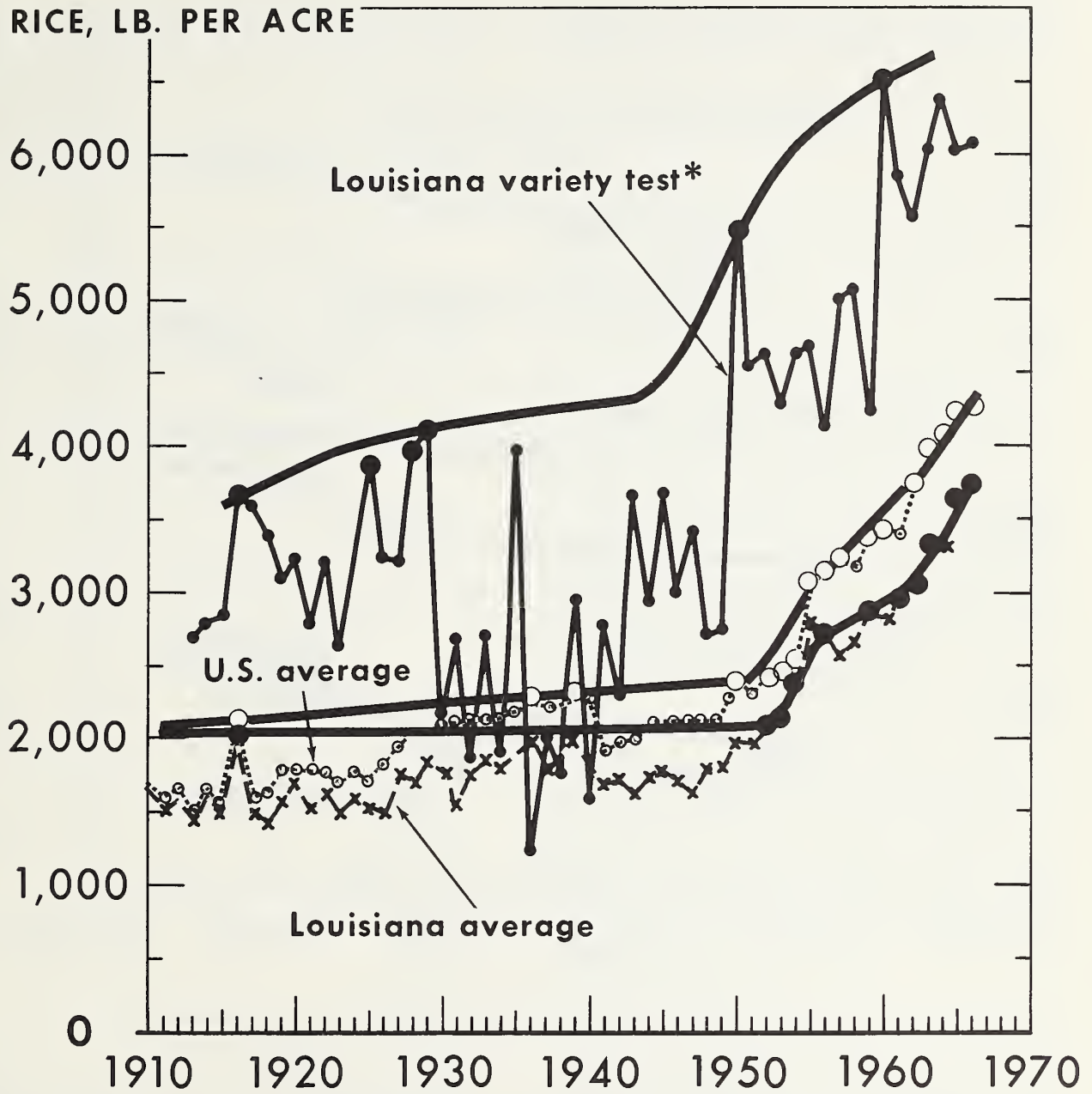


FIGURE 4.—Pork production per 100 pounds of feed.

RICE, LB. PER ACRE



*HIGHEST YIELD.

FIGURE 5.—Rice production per acre.

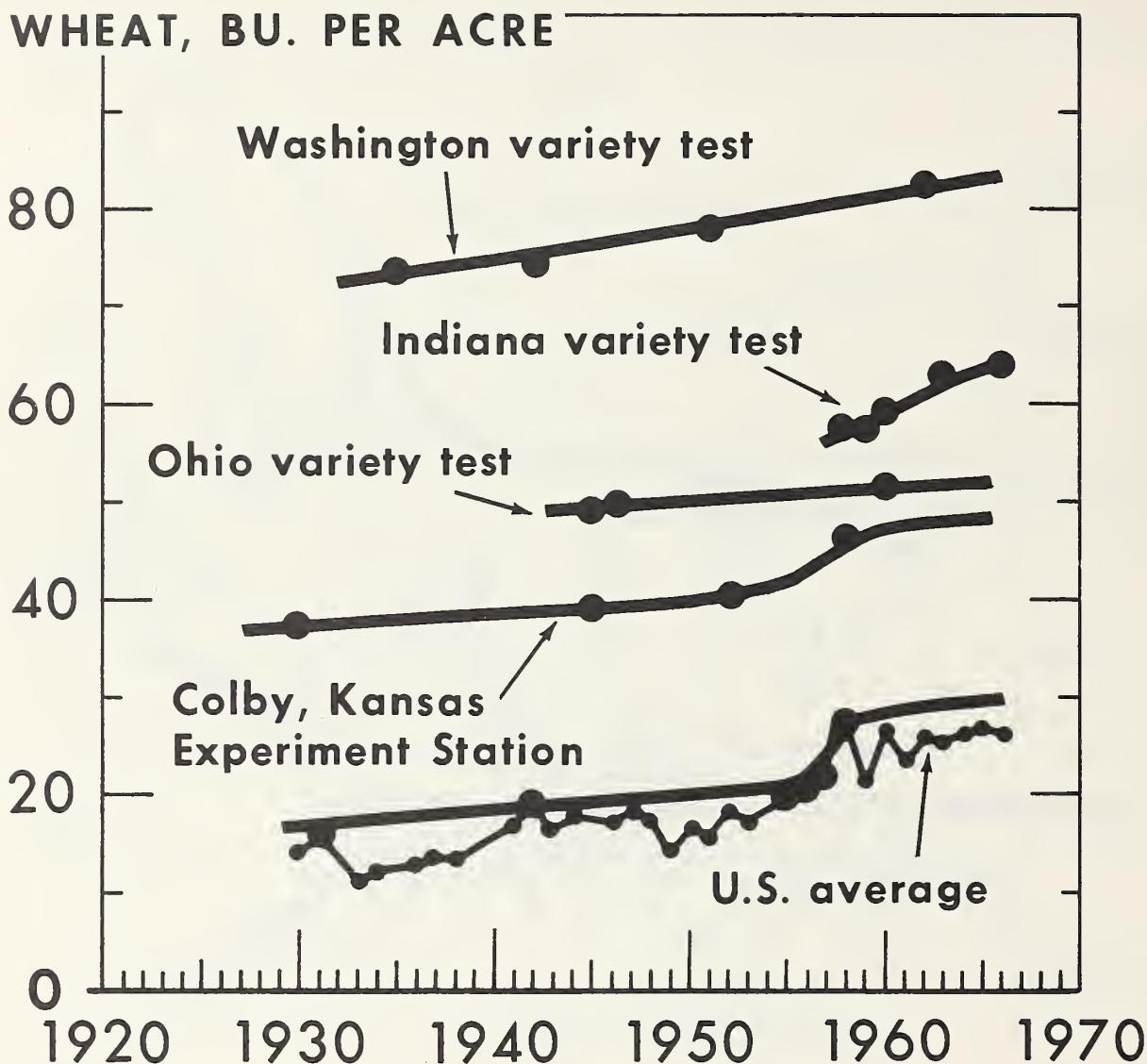


FIGURE 6.—Wheat production per acre.

The curve labeled Colby, Kansas Experiment Station,¹⁵ representing the dry plains, was based on data from plots having the best treatments for the years prior to 1950 and from the variety test at Colby from 1950 to 1966. The plots having the best treatments were discontinued. Yields are plotted for those years that exceeded any previous yields.

The U.S. average wheat yield from 1930 to 1966 is also shown in figure 6.

¹⁵ Data furnished by E. E. Banbury, Superintendent of Colby Branch Station, Kansas Agricultural Experiment Station.

The research frontier in wheat production has advanced slowly but steadily since 1930. A tremendous effort is required in wheat research just to stay even. New diseases develop almost as fast as the scientists can develop new varieties. It was necessary in Washington to change wheat varieties five times in 20 years because the previously used varieties succumbed to smut and stripe rust.

Average wheat production per acre in the United States advanced slowly until about 1955. Then it made a big jump in 1958 and has remained at a higher level since. This has been due to better varieties, control of insects, diseases, and weeds, and increased fertilizer use. Since 70 percent of the

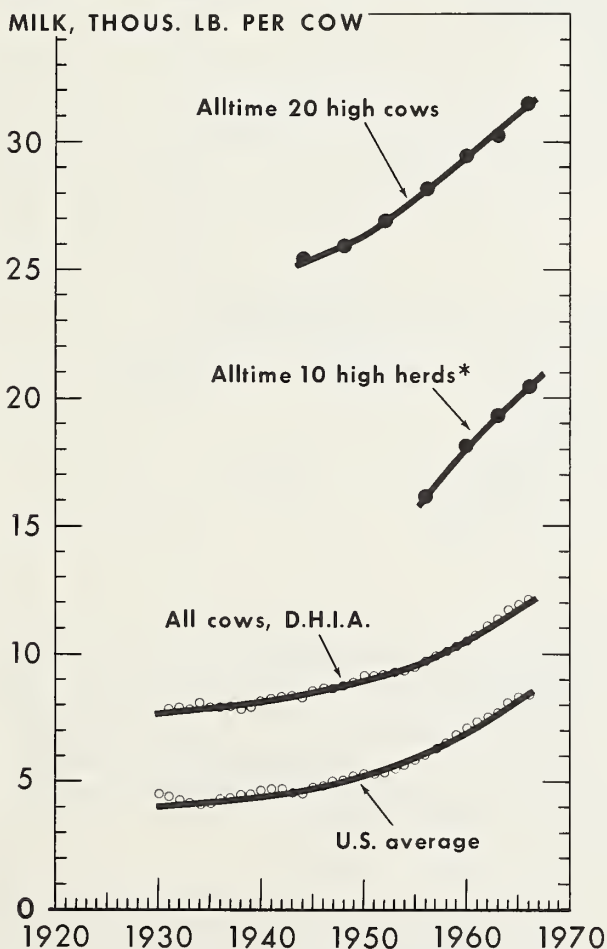
wheat acreage is in the Plains States, it is natural that the smooth curve for U.S. average wheat production per acre resembles the research curve for the Plains (Colby) more than the other three research curves.

Unless research is stepped up considerably, it is unlikely that U.S. average wheat production will be above 30 bushels per acre in the period 1980 to 1985.

Milk Production per Cow

The research frontier in milk production per cow is represented in figure 7 as the average production of the alltime 20 high cows from 1944 to 1966 and the alltime 10 high herds from 1956 to 1966 in the United States.¹⁶ It is apparent that

¹⁶ Data taken from Holstein-Friesian Type and Production Yearbooks, 1944 to 1966. All records adjusted to 2×305 mature basis.



* 31-50 COWS PER HERD.

FIGURE 7.—Milk production per cow.

through research in breeding, nutrition, disease control, and other aspects of dairy management we have made outstanding progress in recent years. The average production of the alltime 20 high cows and the alltime 10 high herds (31-50 cows) increased at an average annual compound rate of 1.12 and 2.38 percent, respectively, from 1956 to 1966.

The payoff from this new information is reflected in the two lowest curves for all cows in the Dairy Herd Improvement Association (D.H.I.A.) and all cows in the United States. The adoption of artificial breeding, improved feed formulas, disease control, and other research findings has helped to spread high-producing blood and good feeding and management techniques to an ever wider group of producers. U.S. milk production increased at an average annual compound rate of 3.4 percent between 1956 and 1966. This was almost twice the 1.74 percent achieved between 1936 and 1956. It is also considerably faster than the rate attained between 1956 and 1966, as shown in the two top curves representing the research frontier. Considering that the rate of increase in these curves seems to be slowing down, it would appear that we need to step up research if we are to maintain the progress made the last 10 years in U.S. milk production per cow. Even so, the U.S. average is expected to continue increasing for some time.

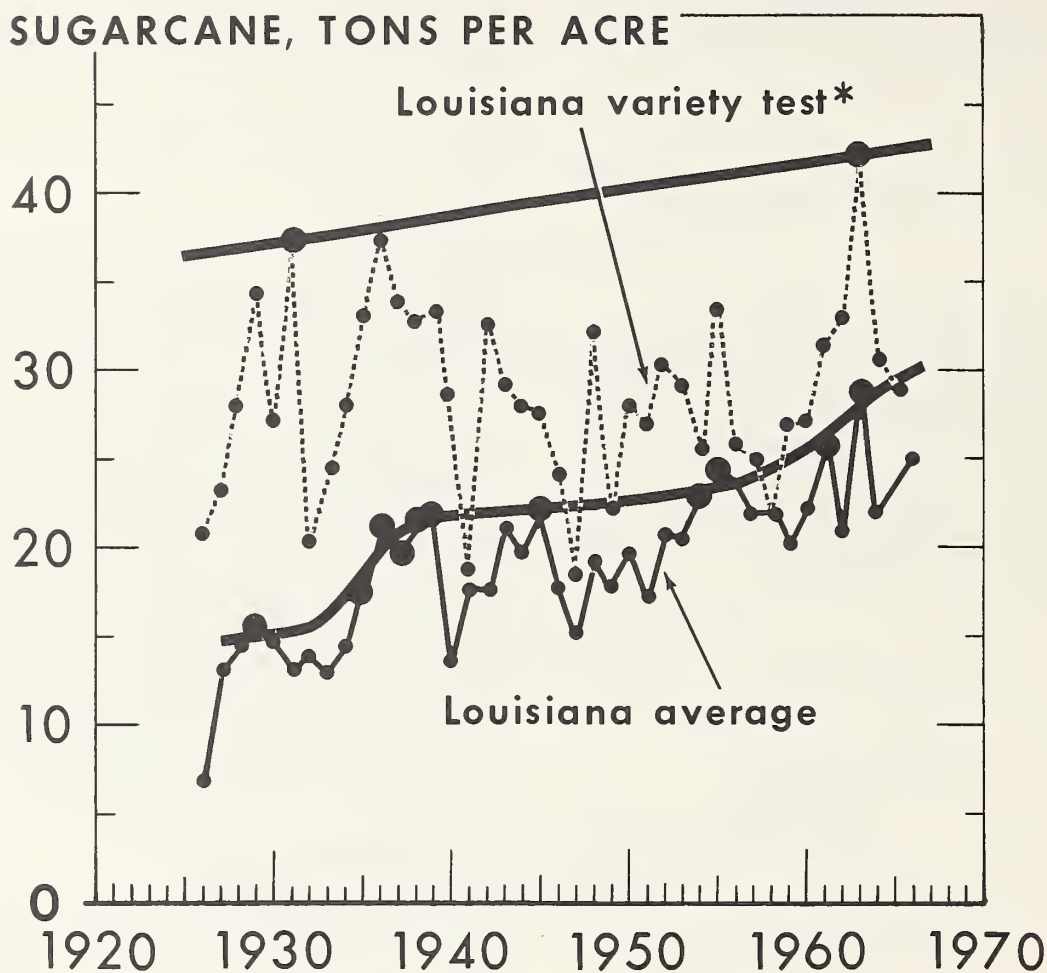
Sugarcane Production per Acre

It takes a lot of running to keep from falling back in sugarcane production research. As seen in figure 8, the average yields in the Louisiana Variety Test¹⁷ from 1937 to 1962 were considerably lower than those obtained earlier. Diseases, particularly ratoon stunting disease and mosaic, caused most of the decline. Only in the last few years have techniques been developed to deal with these problems. As a result, the average research yield in 1963 reached a new high.

Louisiana farm yields increased in the late thirties as a result of research gains between 1925 and 1935. The maximum yield then stayed at about 22 tons per acre for the next 15 years. The maximum yield increased to 24.4 tons in 1955, 25.7 in 1961, and 28.9 in 1963 as farmers took advantage of the new information on disease control.

Average farm yields of sugarcane in Florida and Puerto Rico have followed essentially the same trends as in Louisiana. In Hawaii, where yields are much higher, the maximum average yield went from 80.4 tons in 1952 to 92.9 in 1955, 94.7 in 1964, and 102.6 in 1966.

¹⁷ Data furnished by Crops Research Division, U.S. Department of Agriculture, and Louisiana Agricultural Experiment Station.



* AVERAGE YIELD OF ALL VARIETIES.

FIGURE 8.—Sugarcane production per acre.

If research can keep ahead of diseases, we should maintain the higher yields of sugarcane achieved in recent years. But this is a big "if." A strengthened research program would give us more assurance that we can hold onto and improve on recent gains.

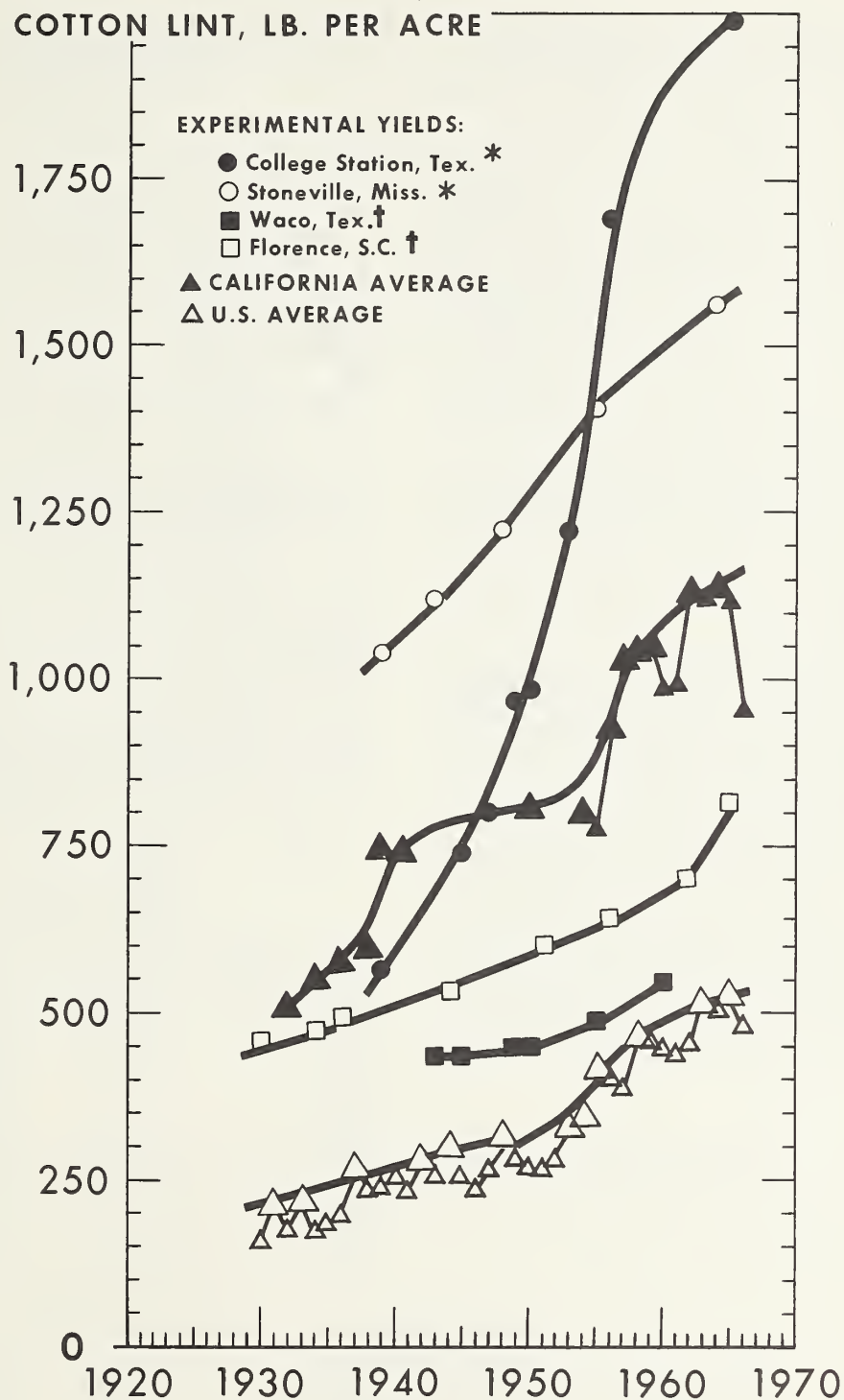
Cotton Lint Production per Acre

Conditions under which cotton is grown vary considerably in the United States. The trends in experimental yields of cotton lint are shown in

figure 9 for College Station¹⁸ and Waco,¹⁹ Tex., Stoneville, Miss.,¹⁸ and Florence, S.C.¹⁹ The plotted points on the curves for these locations are for yields exceeding any yields previously achieved. The curves thus represent what was possible under most favorable conditions using research information.

¹⁸ Data furnished by Crops Research Division, U.S. Department of Agriculture.

¹⁹ Data furnished by Entomology Research Division, U.S. Department of Agriculture.



*HIGHEST EXPERIMENTAL. † AVERAGE OF INSECTICIDE TREATMENTS.

FIGURE 9.—Cotton lint production per acre.

It is apparent that research knowledge about cotton growing has improved substantially since 1930. The rate of increase in research yields at Florence is still accelerating, but at Stoneville and College Station it seems to have reached a maximum and is now slowing down. At Waco the situation is unclear. The rate to 1960 was accelerating, but by 1966 the 1960 yield had not been exceeded.

Average farm cotton lint yields in California and the United States are also shown in figure 9. In California between 1932 and 1954 only those yields that exceeded any previous yields are shown. The California and U.S. average yields increased 125 and 149 percent during 1932-64 and 1931-65, respectively.

Before we can adequately assess the effect of research on cotton lint yields we need to consider the wide fluctuation in acreage from which cotton was harvested during the timespan under consideration. Cotton harvested acres increased gradually from 7.7 million in 1866 to 44.6 million in 1926, then decreased to 17 million in 1945, and rose again, reaching a high of 27.4 million in 1949. The acreage has declined since 1949, and in 1966 it was down to 9.6 million acres.

After the harvested acreage reached a maximum in 1926, one would expect that reduced acreage would lead to increased yields. Farmers had found out how the different fields responded to cotton. If total acres were reduced, one would expect that less productive land would be eliminated first. If this is so, then when acreage is decreasing, any gain in cotton lint yield with time would be a composite of the increases due to decreased acres and new technology.

In figure 10 are plotted 5-year running averages (so as to smooth out year-by-year fluctuations) of reciprocal harvested acres and cotton yields from 1926-30 to 1962-66. The yield curve has four segments of different slopes corresponding to the following four periods: 1926-30 to 1940-44, 1941-45 to 1949-53, 1950-54 to 1955-59, and 1956-60 to 1962-66.

If we assume that the effects of acreage and technology on yield may both be different for each segment of the curve, we should be able to separate the effects of acreage and technology on yield with an equation of the type

$$y = c + bx + d_2Z_2x + d_3Z_3x + d_4Z_4x + at + e_2Z_2t + e_3Z_3t + e_4Z_4t$$

where y = 5-year average yield in pounds per acre
 x = 5-year average reciprocal harvested acres $\times 10^{10}$
 t = time in years from 1925 to 1929
 Z_2, Z_3, Z_4 = dummy variables having a value of 1 in the time periods corresponding to the subscripts and values of 0 in other periods

$c, b, d_2, d_3,$

d_4, a, e_2, e_3, e_4 = constants with $b, d_2, d_3,$ and d_4 relating to acreage and $a, e_2, e_3,$ and e_4 relating to technology

Evaluating the constants in the general equation by the method of least squares, we get

$$y = 130.76782 + 0.10469x - 0.00043Z_2x + 0.32714Z_3x - 0.15933Z_4x + 5.46951t - 0.83190Z_2t - 5.49306Z_3t + 5.48219Z_4t$$

This gives a standard error of estimate for y of 6.4 pounds per acre and a coefficient of multiple correlation between y and the other variables of 0.998.

From the general equation it follows that the equations for the four time periods are

$$y_1 = 130.76782 + 0.10469x + 5.46951t$$

$$y_2 = 130.76782 + 0.10426x + 4.63761t$$

$$y_3 = 130.76782 + 0.43183x - 0.02355t$$

$$y_4 = 130.76782 - 0.05464x + 10.95170t$$

The calculated values of the 5-year running averages of cotton yield, using these equations, are compared with the actual yield in table 3. The calculated and actual values are reasonably close.

TABLE 3.—Comparison of calculated and actual values of U.S. cotton lint yields per acre from 1926-30 to 1962-66

Period	Calculated yield		Actual yield	Difference
	Pounds	Pounds		
	$y_1 = 130.76782 + 0.10469x + 5.46951t$			
1926-30	161.0	167.8	167.8	4.1
1927-31	167.3	171.6	171.6	2.5
1928-32	173.0	173.9	173.9	.5
1929-33	180.3	183.8	183.8	1.9
1930-34	188.4	185.3	185.3	1.7
1931-35	196.7	190.9	190.9	3.0
1932-36	204.1	188.5	188.5	8.2
1933-37	210.1	207.7	207.7	1.2
1934-38	216.8	212.4	212.4	2.1
1935-39	223.2	225.6	225.6	1.1
1936-40	229.7	239.1	239.1	3.9
1937-41	237.3	245.6	245.6	3.4
1938-42	246.7	246.1	246.1	.2
1939-43	253.2	249.7	249.7	1.4
1940-44	260.4	262.0	262.0	.6
	$y_2 = 130.76782 + 0.10426x + 4.63761t$			
1941-45	255.5	262.4	262.4	2.6
1942-46	262.6	263.1	263.1	.2
1943-47	267.9	262.0	262.0	2.3
1944-48	271.8	273.4	273.4	.6
1945-49	272.5	269.9	269.9	1.0
1946-50	276.8	272.9	272.9	1.4
1947-51	277.5	279.6	279.6	.8
1948-52	280.5	282.3	282.3	.6
1949-53	284.6	284.9	284.9	.1

TABLE 3.—Comparison of calculated and actual values of U.S. cotton lint yields per acre from 1926-30 to 1962-66—Continued

Period	Calculated yield		Actual yield	Difference
	Pounds	Pounds		
	$y_3 = 130.76782 + 0.43183x - 0.02355t$			
1950-54	318.9	296.7	7.5	
1951-55	320.6	326.3	1.7	
1952-56	341.7	354.2	3.5	
1953-57	370.6	375.8	1.4	
1954-58	409.9	404.2	1.4	
1955-59	425.4	428.2	.5	
	$y_4 = 130.76782 - 0.05464x + 10.95170t$			
1956-60	432.0	434.0	.5	
1957-61	443.0	439.8	.7	
1958-62	455.0	453.6	.3	
1959-63	467.1	463.8	.7	
1960-64	477.6	475.0	.5	
1961-65	487.7	491.0	.7	
1962-66	495.2	499.8	.9	

It is now possible to separate the effects of acreage and new technology on cotton yields during the different periods. The results are shown in table 4. The greatest gain from research is in the most recent period.

Discussion

The findings in this report on the relationships between research yields and farm yields of principal agricultural commodities during the last 20 to 30 years have been summarized in tables 5-7. In table 5 the absolute differences between re-

TABLE 4.—Average annual increases in U.S. cotton yields per acre from 1926-30 to 1962-66

Period	Calculated increase due to—		Total increase	
	Change in harvested acres	New technology	Calculated	Actual
	Pounds	Pounds	Pounds	Pounds
1926-30 to 1940-44	1.63	5.47	7.10	6.73
1941-45 to 1949-53	-1.00	4.64	3.64	2.81
1951-55 ¹ to 1955-59	26.23	-.02	26.21	25.48
1956-60 to 1962-66	-.42	10.95	10.53	10.97

¹ 1950-54 was not used because of large error in calculated value for this period (see table 3). If 1950-54 is used, respective values are 21.33, -0.02, 21.31, and 26.30.

search and farm yields are shown. For eggs per layer and wheat per acre, the spread between research and farm yields has been decreasing for 30 and 20 years, respectively. For corn and rice, the spread increased during the first 20 years, but it has remained unchanged in the last 10 years. The spread has widened for potatoes per acre and milk per cow for the last 20 years. For cotton, the spread increased in the last 10 years.

Before drawing conclusions on the implications of these data as to the adequacy of agricultural research, let us look at table 6. Farm yields are shown as a percentage of research yields. For every commodity except rice, farm yields have become a higher percentage of research yields at each succeeding 10-year interval.

TABLE 5.—Absolute differences between research yields and farm yields of principal U.S. agricultural commodities at 10-year intervals from 1931-35 to 1961-65

Commodity ¹	1931-35	1941-45	1951-55	1961-65
Eggs.....number per layer.....	99.2	70.9	46.1	25.3
Corn.....bushels per acre.....	49.8	53.8	61.5	61.1
Potatoes, white.....hundredweight per acre.....	229.4	179.8	252.2	273.4
Rice.....pounds per acre.....	478.4	1,062.8	1,999.8	2,079.8
Wheat.....bushels per acre.....		26.5	20.9	19.8
Milk ²pounds per cow.....		20,983	22,637	23,728
Cotton lint.....pounds per acre.....		334.1	333.8	458.0

¹ Pork is not included in tables 5-7 because increased spread in recent years between research and farm yields of pork products per 100 pounds of feed is due to little progress in research and decline of farm yields. Sugarcane is not included because this crop was not analyzed on a national basis.

² Research yields were for 1946, 1956, and 1966, respectively, for data in last three columns.

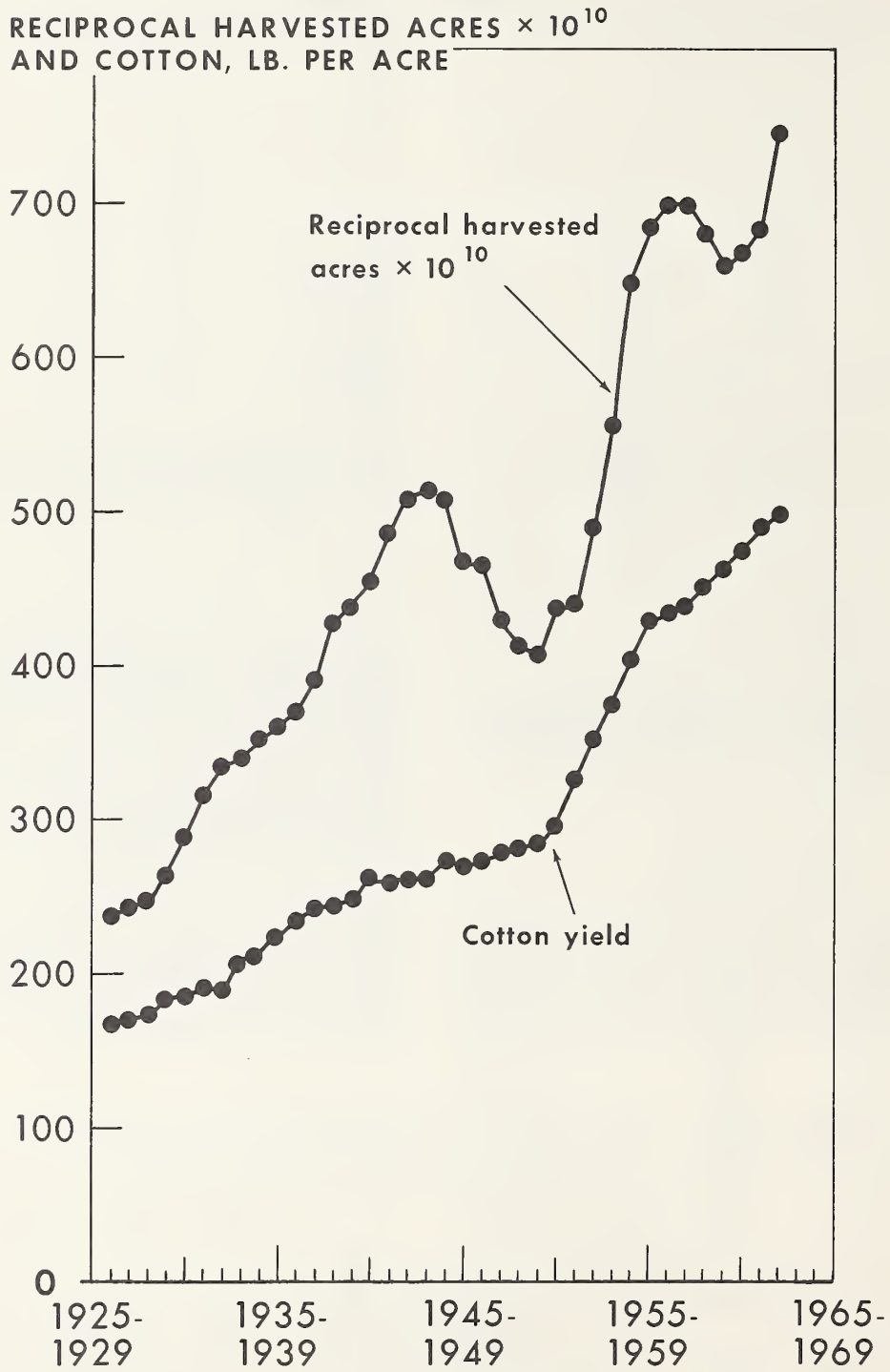


FIGURE 10.—5-year running averages of reciprocal harvested acres and cotton yield.

TABLE 6.—*Farm yields as percentage of research yields for principal U.S. agricultural commodities at 10-year intervals from 1931-35 to 1961-65*

Commodity	1931-35	1941-45	1951-55	1961-65
	Percent	Percent	Percent	Percent
Eggs.....number per layer..	55.0	67.1	80.0	89.4
Corn.....bushels per acre..	31.2	37.8	39.5	51.9
Potatoes, white.....hundredweight per acre..	22.0	32.2	37.7	41.8
Rice.....pounds per acre..	81.7	65.4	56.0	65.2
Wheat.....bushels per acre..		39.8	46.1	56.2
Milk ¹pounds per cow.....		18.3	19.7	24.7
Cotton lint.....pounds per acre.....		44.0	49.4	51.7

¹ Research yields were for 1946, 1956, and 1966, respectively, for data in last three columns.

These data provide evidence of the effectiveness of educational and other efforts in the United States to translate research information into farm practice. It is not expected that average farm yields will ever equal research yields. What the maximum attainable percentage might be is unknown. Very likely it will be different for various commodities. It seems unlikely that average corn yields could ever become 89 percent of research yields, as achieved for eggs per layer. In any event, the closer farm yields approach research yields, the smaller becomes the backlog of unused information and the more difficult it becomes to increase agricultural productivity through education. Education then becomes a more limited alternative to research.

It would seem that a favorable position for the Nation would be one in which new agricultural research findings were being developed at a rate equal to or preferably greater than the rate at which current findings were being used. We would

then have at all times some unused potential that could be utilized in an emergency. We would also have more assurance of meeting the Nation's needs as demands on agriculture increase.

Our current position in agricultural research is unfavorable. As shown in table 7, we have not been turning out new research findings in the last 10 years at a rate equal to that at which they are being used. For every commodity, farm yields have been increasing faster than research yields.

Many aspects of agricultural production have not been considered in this study. No mention has been made of utilization and marketing. However, the sampling is considered adequate to show that much of our reserve of scientific knowledge has been used in the last several years. Under these conditions we can expect a slower increase in farm yields in the future unless the research frontier begins to advance faster than it has in the last 10 years.

I conclude that agricultural research knowledge is not being developed fast enough.

 TABLE 7.—*Average annual compound change in research and farm yields of principal U.S. agricultural commodities from 1951-55 to 1961-65*

Commodity	Research yield	Farm yield
	Percent	Percent
Eggs.....number per layer..	0.35	1.48
Corn.....bushels per acre..	2.25	5.07
Potatoes, white.....hundredweight per acre..	1.49	2.56
Rice.....pounds per acre..	2.76	4.32
Wheat.....bushels per acre..	1.54	3.56
Milk.....pounds per cow..	¹ 1.12	3.48
Cotton lint.....pounds per acre..	3.70	4.17

¹ 1956-66.

